EVALUATING THE EFFECTIVENESS OF WILDLIFE PASSAGE STRUCTURES ON THE BENNINGTON BYPASS

Final Report

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16. Abstract

The Bennington Bypass project used a broad, multi–taxa approach to monitoring crossing structures on a newly constructed highway in southern Vermont. We utilized a variety of techniques to assess movements of an array of species at the passage structures and in the surrounding landscape.

Study results indicate that many species of wildlife are using the passages to cross the highway. Although pre-construction data were not available for comparison, the crossing structures appear to be adequately mitigating impacts for mink, otter, and ermine. Data indicate that the passage structures are providing some passage for deer/white-footed mice. Although the resistance to movement for the crossing structures is higher than for natural habitat, the rate of *Peromyscus* passage appears to be high enough to maintain gene flow and other metapopulation dynamics.

Animals are generally able to get over or under the right-of-way fencing and some species (raccoon, skunk, opossum, coyote, bobcat and deer) continued to cross over the road surface in high numbers. High numbers of crossings over the road surface relative to those through the crossing structures suggests that the mitigation has been only partially successful for fisher, coyote, bobcat and deer. Mitigation success for deer appears to be improving over time and it is possible that as wildlife become more accustomed to the structures and vegetation and coarse woody debris continue to develop within the structures, mitigation success will improve for other species as well.

Far fewer crossings were recorded for long-tailed weasels than for ermine. Moose, black bear, red and gray foxes were not recorded using the crossing structures and were not documented

by snow tracking as having crossed the highway at all. It is possible that these species are avoiding the highway alignment.

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EXECUTIVE SUMMARY

The Bennington Bypass (Hwy. 279) is an 18-km long highway designed to alleviate traffic congestions in the downtown Bennington area. The first segment (called the Western Segment) of the 3-phase highway is 7-km long and connects NY Rte. 7 in Hoosick Falls, NY to US Rte.7 in Bennington, VT. This segment of the highway opened in October 2004 and included three wildlife crossing structures; two expanded bridges and a long culvert. This study monitored the effectiveness of these crossing structures and compared rates of wildlife movement across the highway in mitigated and unmitigated sections. The specific project objectives were to:

1. Assess the impact of the highway on wildlife movements.
2. Evaluate the effectiveness of wildlife passage structures for mitigating those impacts.
3. Establish a baseline for assessing long-term impacts of the highway on wildlife populations and the effectiveness of mitigation.
4. Test and refine monitoring techniques for use on the proposed VT Route 78 and other highway projects both in Vermont and Nationwide.
5. Serve as a model for the proper integration of transportation, wildlife passage structures and complimentary research for both the Northeast Region as well as the Nation.
6. To improve the ability of other states in the region and throughout the United States to understand and address the effects of new road development on wildlife and ecosystems.

We used track beds and remote cameras to determine the use of two large extended bridge crossing structures and track plates to determine use of a long, narrow culvert on the Bennington Bypass in southern Vermont. We recorded 786 sets of animal tracks ($\geq$26 taxa) on track beds over 349 track nights during three field seasons for the two large crossing structures. The numbers of crossings differed between the two crossing structures for several species, especially white-tailed deer and woodchuck. Using indices, we detected significant differences ($P = 0.020$) in monthly track bed crossings with the highest crossing index in May and the lowest in July. Digital cameras at track beds during two field seasons recorded 65 observations of animals, behaviors which were critical in our analysis of two species, white-tailed deer and woodchuck. Cameras mounted along streams recorded 90 animal crossings of six species. The additional crossing data recorded by the cameras increased the overall numbers of structure crossings for six species by 38% in 2006 and 41% in 2007, with bobcat, raccoon, deer, and turkey accounting for the majority of these increases.

Using track plates, we recorded relatively few mammals using the narrow culvert, with the exception of ermine. Although track beds were effective for recording a wide variety of vertebrate taxa moving in a crossing structure, we were not always able to identify tracks to the species level. Cameras were critical for recording behaviors at track beds and evaluating the effectiveness of track beds for recording crossings. Track beds and remote cameras only provide an index to crossing structure use because individuals typically cannot be identified. In lieu of population studies, the combination of track beds and cameras provided the most accurate assessment of crossing structure use in our study area.

A variety of strategies, primarily in the form of underpasses and overpasses, have been used with mixed success to mitigate the impacts of transportation systems on wildlife. Although the construction of such structures is increasing, limited research has been conducted to assess their efficacy. Structures that were monitored for effectiveness focus primarily on passage use with less consideration given to animal movements in the surrounding landscape. We used snow-tracking as a means to determine permeability of the roadway and to evaluate differences in use of the road vs. the crossing structures for movement through the landscape of the nine species for which we recorded tracks. We analyzed our data using a conceptual model of movement. Based on sets of tracks, our results indicate that the roadway appears to be permeable for most species in our study area and that use of the crossing structures relative to the road increased over the two years of our study, primarily due to increased use by white-tailed deer. Overall, the structures mitigate some of the barrier effect created by the road but many animals remain vulnerable to vehicle collision. Our study underscores the need for well defined pre-construction objectives and landscape scale monitoring of wildlife crossing structures.

Wildlife/vehicle collisions (WVC) represent one of the most direct impacts that road systems have on both wildlife and people. These collisions yield human costs in property damage and bodily injury or even death, and a cost to wildlife through elevated mortality rates. Wildlife crossing structures are being constructed as a means to mitigate WVCs and other road impacts. We used road kill surveys to determine the efficacy of two wildlife crossing structures at the Bennington Bypass in southern Vermont in addition to determining correlations between traffic volume and road kill numbers. We tested the hypothesis that road kill numbers would be positively correlated with increasing distances from the structures and with increasing traffic volumes. We found that road kill numbers do not vary with distance from the crossing structures. There was also only a slight positive correlation between average daily traffic (ADT) and number of road kill. There are several possible causes for the apparent lack of road kill reduction associated with the crossing structures.

Roadways impose a variety of impacts on wildlife, especially small mammals that have limited dispersal capabilities and low probability of surviving highway-crossing attempts. Crossing structures are used to mitigate impacts of roads on wildlife, but these structures are typically intended for large mammals. We assessed whether small mammals are using two extended bridge crossing structures in Bennington, VT. We used mark-recapture monitoring to determine the extent that small mammals moved across the roadway and through the crossing structures. Of 684 small mammals captured and tagged, 378 were recaptured at least once and 138 moved $\geq$65m. We detected only 13 individual small mammals that moved through the two crossing structures and one individual that crossed the roadway away from the structures. The roadway poses a barrier to movements by small mammals and only a few small mammals used the crossing structures to move across the roadway. The steep roadway embankments, large openness ratio of structures, and limited natural vegetation at structure openings may reduce the numbers of small mammals moving through the crossing structures.

Study results indicate that many species of wildlife are using the passages to cross the highway. Although pre-construction data were not available for comparison the crossing structures appear to be adequately mitigating impacts for mink, otter, and ermine. Data indicate that the passage structures are providing some passage for deer/white-footed mice. Although the resistance to passage for the crossing structures is higher than for natural habitat, the rate of *Peromyscus* passage appears to be high enough to maintain gene flow and other metapopulation dynamics.

Animals are generally able to get over or under the right-of-way fencing and some species (raccoon, skunk, opossum, coyote, bobcat and deer) continue to cross over the road surface in high numbers. High numbers of crossings over the road surface relative to those through the crossing structures suggests that the mitigation has been only partially successful for fisher, coyote, bobcat and deer. Mitigation success for deer appears to be improving over time and it is possible that as wildlife become more accustomed to the structures and vegetation and coarse woody debris continue to develop within the structures, mitigation success will improve for other species as well.

Far fewer crossings were recorded for long-tailed weasels than for ermine. Moose, black bear, and red fox were not recorded using the crossing structures and were not documented by snow tracking as having crossed the highway at all. It is possible that these species are avoiding the highway alignment.

Recommendations for the Current Study Site

1. Replace right-of-way fencing with barrier fencing for the entire area between WAB and EAB and for 2km beyond the expanded bridges in both directions.
2. Develop and implement vegetation management plans for the two expanded bridges to optimize woody plant development compatible with maintenance and operation of the highway.
3. Remove large angular rip rap from the entrances of the culvert or use smaller material (e.g. pea stone) to fill the voids in the rip rap and provide a more suitable substrate for wildlife passage.
4. Add concrete or another suitable substrate material to culvert bottom throughout the entire length to provide a more suitable alterative to the corrugated metal bottom wildlife must now use when passing through the structure.
5. If it is not possible to create a more suitable bottom for the culvert, then remove sills originally intended for trapping and retaining sediment within the structure.
6. Repeat select components of this study (small mammal trapping; snow tracking) after the passage of about ten years to better assess changes in mitigation success over time or in response to changes made to fencing or the structures themselves.

Recommendations for Future Projects

1. Develop clear mitigation objectives for each species or group of species that are the targets for mitigation; consider the use of metrics to evaluate mitigation

success.

2. Ensure that barrier fencing is an element of any mitigation design for terrestrial wildlife.
3. Include consideration of vegetation, including the potential need for vegetation management, as part of mitigation design
4. Conduct pre-construction monitoring of wildlife movement to identify game trails that might suggest suitable locations for mitigation structures and provide a basis for comparison with post-construction data to more effectively evaluate mitigation success.
5. Use a variety of monitoring techniques (snow tracking, small mammal trapping, track beds and remote cameras) to monitor crossing structures for the broadest range of wildlife species.
6. Use Frogloggers or other suitable technique for pre- and post-construction monitoring to assess changes in amphibian populations as a result of highway projects.

CHAPTER 1.

INTRODUCTION

Roads are prominent, contiguous features covering approximately 1% of the United States land mass (Forman and Deblinger 2000) and have been built for decades with little consideration for ecological effects. Increasingly, the impacts of roads are being recognized and the science of road ecology has emerged as an important area of study for conservation biologists. For wildlife, the impacts of roads are disproportionate to the area of land they occupy (Reed et al. 1996, Forman and Alexander 1998, Jackson and Griffin 2000).

Direct impacts on wildlife include mortality via vehicle collision and restriction or alteration of movement (Forman et al. 2003). Road kill exceeds hunting as the leading direct human cause of vertebrate mortality, with approximately one million vertebrates a day killed on roads in the United States (Putman 1997). Roadways also affect wildlife through habitat loss and fragmentation, isolation of wildlife populations, disruption of gene flow and metapopulation dynamics (Andrews 1990, Bennett 1991, De Santo and Smith 1993, Trombulak and Frissell 2000).

A variety of strategies have been used with mixed success to mitigate the impacts of roads on wildlife (Jackson and Griffin 1998). Commonly, underpasses are used to facilitate movement of wildlife across roadways in Europe, Australia, Canada and the U.S. (Cramer and Bissonette 2005). However, the effectiveness of these underpasses to facilitate wildlife movement depends on a number of variables, including: size, proximity to natural wildlife corridors, noise levels, substrate, vegetative cover, moisture, temperature, light, and human disturbance (Jackson and Griffin 2000). For example, cover can play a key role in passageway effectiveness for small mammals. The installation of gutters in culverts significantly increased small mammal movement (Foresman 2004*a*, Foresman 2004*b*). Numerous studies report the importance of vegetation at crossing structure entrances to enhance use by wildlife (Hunt et al. 1987, Clevenger and Waltho 2000, Cain et al. 2003). Further, different species typically have different requirements. Thus if crossing structures are designed for use by a single species, they may constitute an absolute barrier for other species that have different requirements (Barnum 2004).

Most attempts to evaluate wildlife crossing structures focus exclusively on documenting wildlife use of structures (Forman et al. 2003). While tracking beds, cameras, and counters document the species using structures, they provide little information on those species or individuals that fail to use a structure. In contrast, telemetry, trapping and tracking studies are more useful for determining the extent to which roadways inhibit wildlife movements and the degree to which crossing structures mitigate these effects (Cain et al. 2003, McCoy 2005). Thus, to fully assess the effectiveness of wildlife passageways, a combination of monitoring techniques across a variety of taxa is needed to evaluate structure use impacts of transportation systems on animal movements (Jackson 1999, Hardy et al. 2004).

The goal of this study was to assess the effectiveness of wildlife crossing structures constructed as part of the Bennington Bypass (Highway 279) in southern Vermont. The Western Segment of the bypass was completed in October 2004 and includes three wildlife crossing structures: two extended bridges and a large culvert. This study monitored the effectiveness of these crossing structures and compared rates of wildlife movement across the highway in mitigated and unmitigated sections. The specific project objectives were to:

1. Assess the impact of the highway on wildlife movements.
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4. Test and refine monitoring techniques for use on the proposed VT Route 78 and other highway projects both in Vermont and Nationwide.
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STUDY AREA

The Bennington Bypass (Hwy. 279) is an 18-km long highway designed to alleviate traffic congestion in the downtown Bennington area (Fig. 1.1). It is a 2-lane highway with several 3-lane passing zone areas. The first segment (called the Western Segment) of the 3-phase highway is 7-km long and connects NY Rte. 7 in Hoosick Falls, NY to US Rte. 7 in Bennington, VT. The Bennington Bypass is a moderate to high volume road according to the classification of Alexander et al. (2005*b*). The average daily traffic (ADT) for Highway 279 was 4,674 and 4,882 in year one and two respectively. This segment of the highway opened in October 2004 and included three wildlife crossing structures; two extended bridges and a long culvert.

The bridges were constructed as overpasses over two streams, East Airport Brook and West Airport Brook. The two streams are separated by 0.9km, both occur in the eastern half of the 7km-long bypass and flow north into the Walloomsac River (Fig. 1.2). Both streams are about 2m-wide with East Airport Brook intermittent and West Airport Brook perennial. Both streams are off-center of the crossing structures, closer to the western end of each overpass opening.

The West Airport Brook crossing structure (WAB) is 56.55m long, 8m wide (at base) with a 12m rise (Fig. 1.3). The side slope of the eastern side of West Airport Brook is moderately vegetated (herbaceous, shrub and sapling vegetation) with a gradual (14°), 2.2m high slope. In contrast, there is no vegetation on the western slope of the stream which is covered by rip rap and has a steeper (34°), 7.9m high slope.

The East Airport Brook crossing structure (EAB) is 48.45m long, 8m wide (at base) with an 18m rise (Fig. 1.4). The side slopes of East Airport Brook are heavily vegetated and steep on both the east (39°, 11.2m high) and west sides (47°, 9.1m high) of the stream. There is a 0.6 - 2m-wide game trail under the East Airport Brook structure where the slope (27°) is lower. Both overpasses create relatively large crossing structures underneath the highway, with openness ratios (x-section/length in meters, Reed and Ward 1985) for WAB $\geq$ 86.0m and EAB $\geq$ 97.4m.

The long culvert (crossing structure) is located approximately 200m west of WAB (Fig. 1.5). This 1.65m-diameter, 124m-long culvert connects two stormwater detention ponds located on either side of the highway. The openness ratio of the culvert is 0.02 (2.14m(area)/124m).

Fencing occurs along the entire length of the Bennington Bypass. Most of this consists of 1.2m right-of-way fencing providing a 50m buffer of open land adjacent to the roadway, covered in the spring and summer with grasses and wildflowers. Right-of-way fencing is a common feature of limited access highways in Vermont and was not part of the wildlife crossing design. The right-of-way fencing transitions to 2.4m lead (exclusionary) fencing near each crossing structure entrance, designed to funnel wildlife through the structures (Fig. 1.6). The lead fencing extends approximately 150m from each corner of the crossing structures (4 lead fences per structure). The length and configuration of the fencing differs slightly for each entrance due to topography, variation in vegetation, and the presence of two stormwater detention ponds.

Beyond the right-of-way, the majority of property is private land, consisting of 4-48ha parcels. Sparsely-spaced houses occur on either side of the roadway with most located approximately 300m away from the roadway. The only public land adjacent to the roadway is a 176ha parcel about 1km southwest of WAB owned by the State of Vermont (Vermont Fish and Wildlife) that provides wintering habitat for deer. The vegetation community adjacent to the roadway is a Northern hardwoods broad leaf complex dominated by American Beech (*Fagus grandfolia*), Maple (*Acer spp.*) and Eastern hemlock (*Tsuga canadensis*). Much of the understory is dominated by Canada honeysuckle (*Lonicera Canadensis*).

In Chapter 2, we present the results of research using track beds and remote camera sensing to determine what species use the crossing structures. We also compared the two techniques in their ability to detect species use of the structures. In Chapter 3, we present the results of research conducted using snow-tracking as a method to determine the permeability of the road landscape to wildlife in the study area, and also to compare relative use of the crossing structures to road crossings. In Chapter 4, we present results of road kill surveys which were used to determine if the number of road kills decreased as a function of proximity to the crossing structures and the relationship between traffic volume and numbers of road kills. In Chapter 5, we present the results of a mark-recapture study used to determine if the roadway serves as a barrier to movement for small mammals and in addition to an evaluation of use of the structures by small mammals. Chapter 6 summarizes our evaluation of the effectiveness of the wildlife passage structures and provides recommendations for enhancing the crossing structures and future projects.

The importance of incorporating mitigation for wildlife into highway construction projects is gaining acceptance by many state transportation and natural resource agencies but unfortunately monitoring is currently not a major component of wildlife crossing design. Consequently, more rigorous studies and evaluations of crossing structures are needed to optimize design of these structures. This work is an effort to provide a broader approach to evaluating effectiveness, potentially serving as a template for monitoring techniques and assessment of future wildlife crossing structures, both in Vermont and nationwide.

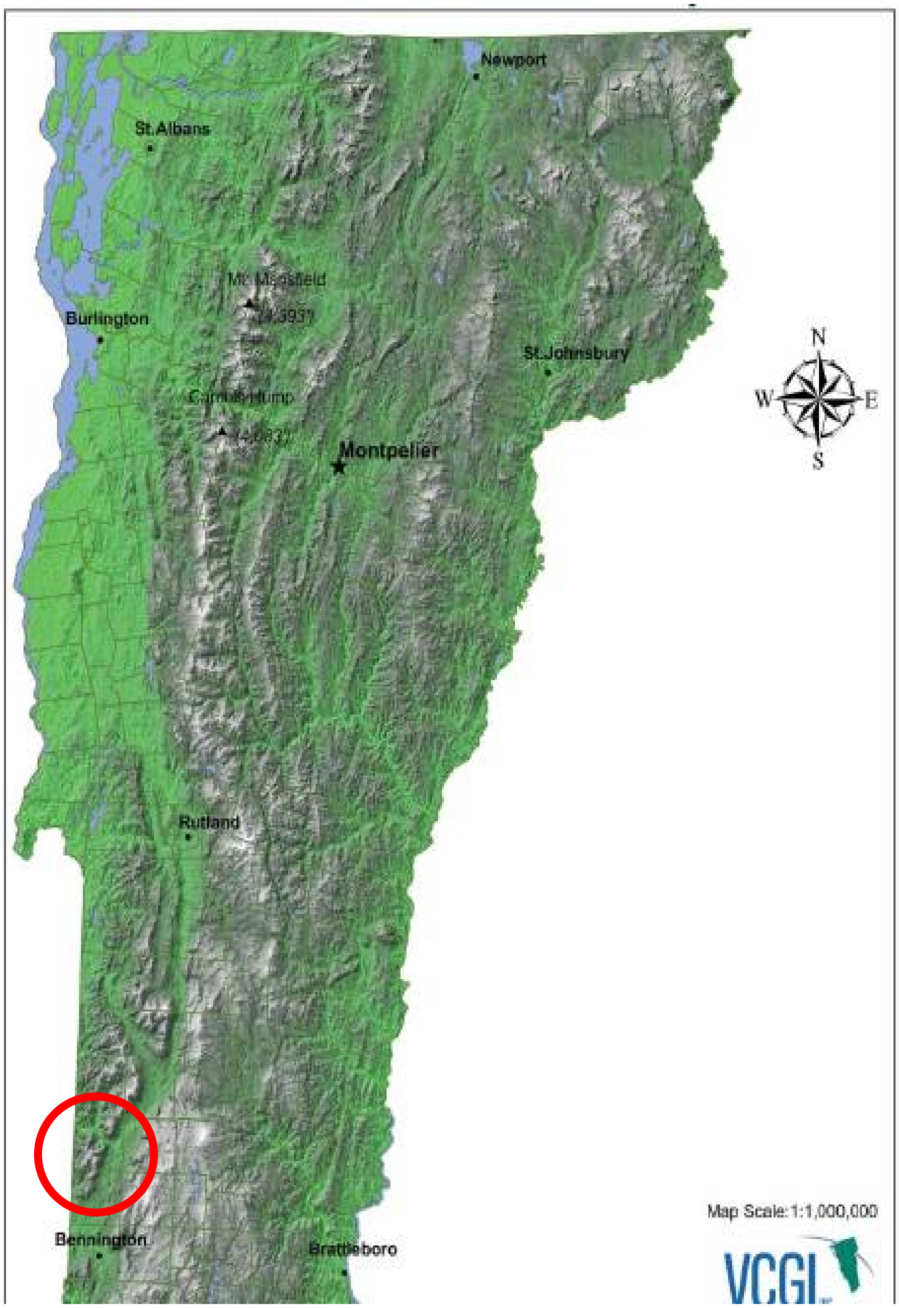

Figure 1.1 Location of the Bennington Bypass (Highway 279) in Southern Vermont.

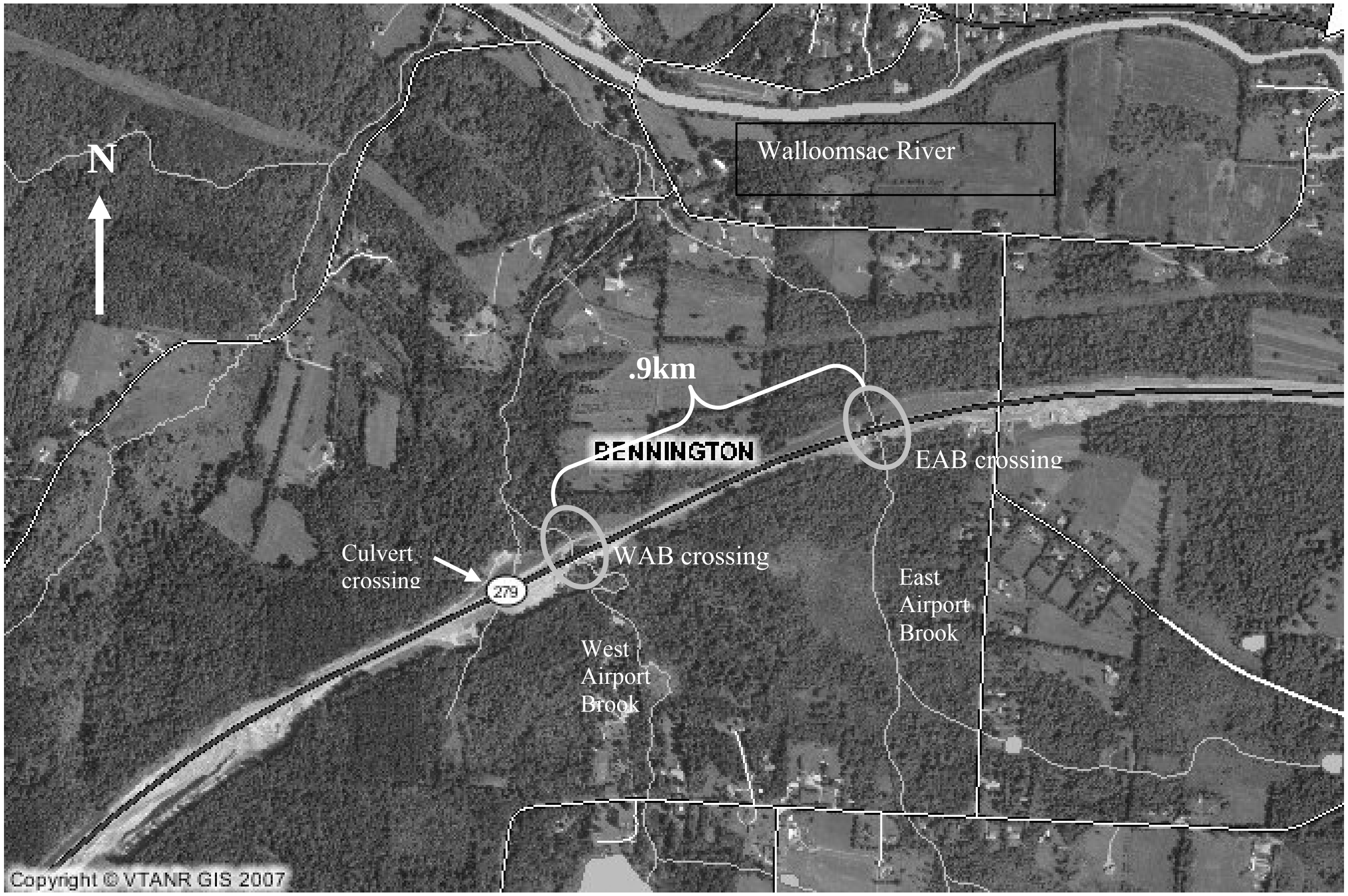

Figure 1.2. Locations of three crossing structures along the 7km-long Highway 279 (Bennington Bypass) near Bennington, VT.

Figure 1.3. West Airport Brook (WAB) crossing structure.

Figure 1.4. East Airport Brook (EAB) crossing structure.

Figure 1.5. Long culvert crossing structure.

Figure 1.6. Barrier and right-of-way fencing.

CHAPTER 2.

USING TRACK BEDS AND REMOTE CAMERAS FOR MONITORING WILDLIFE CROSSING STRUCTURES IN SOUTHERN VERMONT

INTRODUCTION

A wide variety of ecological impacts on wildlife are caused by vehicles and the roadways that carry them. There are both direct and indirect effects, including mortality from vehicles, habitat loss and degradation, habitat and population fragmentation and modification of animal behaviors (Jackson 1999, Trombulak and Frissell 2000). Considerable efforts are being made to mitigate these road impacts, especially the construction of wildlife crossing structures. As of 2005, Cramer and Bissonette (2005) reported there were 460 terrestrial crossing structures in the United States. Yet, relatively few of these structures were monitored for effectiveness (Romin and Bissonette 1996*b*, Clevenger and Waltho 2005, Cramer and Bissonette 2005). In a sample of 21 studies that monitored crossing structure use by wildlife, typically larger carnivores and ungulates were the taxa groups most frequently monitored. Many studies monitored only a single species (Gordon and Anderson 2004, Kaye et al. 2006).

Several monitoring techniques are available for evaluating crossing structure effectiveness, including road kill and vehicle collision data, snow-tracking, track beds and plates, camera and video monitoring, anecdotal information, observational data, radio monitoring, DNA assignment testing and fecal stress measures (Hardy et al. 2004). The most prevalent methods used are track beds and camera monitoring. A summary of 17 studies reviewed by Forman et al. (2003) showed that 71% of the studies utilized track beds (n = 12) and 29% (n = 5) used remote camera sensing. In only two of the 17 studies, were the two techniques used concurrently.

Use of tracks provides a non-invasive means to document species presence, and potentially population trends and relative population densities (Beier and Cunningham 1996, Huijser and Bergers 2000); however, track bed data cannot distinguish between individual animals. Thus, it is difficult to determine if an individual animal is repeatedly using a crossing structure or whether multiple animals are using the structure. Consequently, absolute numbers of animals using a structure cannot be determined. Additionally, effective track beds are typically difficult to construct and monitor.

Remote sensing cameras can overcome some of the limitations of track beds (Kucera and Barrett 1993). We used track beds/plates and remote cameras at three wildlife crossing structures in southern Vermont to 1) determine what species used the crossing structures, and 2) evaluate the effectiveness of track beds/plates and cameras for monitoring crossing structures.

METHODS

Track beds

We constructed track beds along the midline of each crossing structure (Fig. 2.1) by placing 1.2m x 1.2m sheets of 1.2cm-thick Oriented Strand Board (OSB) end to end along the entire width of each crossing structure, except in streams and areas where the vegetation was too dense or slope too steep. The two track bed segments (one on each side of the stream) in WAB were 25.2m and 6m in length, and the two within EAB were 9.6m and 4.8m in length. Next, we placed a fine layer (~2 mm thick) of marble dust on top of the OSB sheets as described by Yanes et al. 1995 (Fig. 2.2).

We inspected and reconditioned track beds one to three times/week following nights without rainfall. We were unable to collect data during periods of disturbance. For each track set we recorded species (or at a minimum, family) and direction of travel. For difficult to identify tracks, we photographed and measured foot width and length, stride and straddle for subsequent identification. If a mammalian family or species could not be determined, we classified tracks as small- (chipmunk or smaller) and medium-sized (larger than a chipmunk) mammals. Track beds were monitored during three field seasons: 28 Apr to 26 Aug 2005 (120 days), 24 Apr to 13 Oct 2006 (173 days), 30 Apr to 8 Oct 2007 (162 days). Each track set was recorded as a track bed crossing. However, a crossing of the track bed does not necessarily mean a crossing through the structure.

We analyzed our data to determine, 1) differences in numbers of crossings per species by structure between years, and 2) monthly differences in numbers of crossings for all species adjusted by number of track nights (Index of Crossing (IOC)). We used the Chi-square test to compare the numbers of species-specific crossings (only for species with $\geq$ 10 crossings excluding *Peromyscus* spp.) between structures by year and all years combined. We used a one-way ANOVA to test for monthly and annual differences in IOC between years by structure, and the overall average (2005-07) IOC between structures.

Track plates

We used two sooted track plates as described by Foresman and Pearson (1998) to monitor wildlife using the culvert crossing structure (Fig. 2.3). Track plates were 1m x 1m aluminum sheets of metal (8 gauge), sooted with an acetylene torch with a 1m x 30cm strip of contact paper placed in the middle of the sheets to record the soot laden footprints of animals. A track plate was placed at each end of the culvert within 5m of the opening. Plates were checked two to three times/week, recording species, date and direction of travel. Only animals with tracks recorded on both track plates were considered to have crossed through the structure.

Remote cameras

Track bed cameras

We used two types of cameras at track beds to record species occurrence and behavior within the crossing structures. A single 35mm camera (TrailMaster TM1050 Active Infrared Trail Monitor, Goodson and Associates, Inc., Lenexa, KS) was used to confirm what species occurred at the track beds (Fig. 2.4). This single camera was rotated between the two crossing structures every month for two (2006 and 2007) field seasons with each segment of the track bed (two per crossing structure) monitored for two weeks before switching to the other side of the stream, except during the first month of both field seasons when two additional digital cameras were used to monitor track beds. The camera was checked weekly and pictures cataloged by date. Although this camera was in place continuously at track beds from 24 May - 13 Oct 2006 (143 days) and 29 May - 8 Oct 8 2007 (133 days), the camera sporadically ran out of film and at other times the triggering mechanism seemed unresponsive.

The second type of camera used at the track beds was a motion-sensing, infrared digital camera (Silent Image Professional Model PM35M13, Reconyx, LLP, Holmen, WI) (Fig. 2.5). Two of these cameras, one at each crossing structure, were used during the first month of two field seasons (24 April - 24 May 2006 (30 days) and 30 April - 25 May 2007 (26 days)) to record species occurrence and behavior at track beds. These digital cameras were equipped with SanDisk 512MB compact flash memory cartridges, and set to record 10 images/trigger at two frames/sec, date and time. We checked/downloaded images from the cameras weekly using MapView Image Management™ (Reconyx, LLP, Holmen, WI).

Stream cameras

After the initial month of monitoring at track beds, the infrared digital cameras were moved to focus on wildlife movements in and adjacent to the stream where it was not possible to install track beds (Fig. 2.6). These cameras were used to record what species were moving through the structures in areas not covered by track beds. These cameras were in place continuously from 24 May - 13 Oct 2006 (143 days) and 29 May - 8 Oct 8 2007 (133 days), and battery failure occurred only rarely. We compared numbers of crossings recorded by these cameras to track bed crossings only for the above dates when both cameras and track beds were operational.

RESULTS

Track beds and plates

We recorded 786 sets of animal tracks on track beds over 349 track nights for the three field seasons, representing at least 26 taxa (Table 2.1). One hundred-ten of the 786 sets of tracks were unidentifiable and recorded as small- (n = 59) and medium-sized (n = 51) mammals. Sixty-two of the 786 tracks were only identifiable to family or genus level including *Ranidae* (n = 2), C*anidae* (n = 3), *Felidae* (n = 4), *Zapodidae* (n = 12) and *Peromyscus* (n = 41).

Eight species had $\geq$ 10 track bed crossings in one or more years (Table 2.1). For these eight species, there were more crossings in WAB than EAB for white-tailed deer (2005, 2006, 2007), Virginia opossums (2006), and woodchuck (2006, 2007), while there were more crossings in EAB than WAB for domestic cats (2006) and wild turkeys (2006, 2007). For all years combined, there were 434 recorded crossings in WAB and 352 recorded crossings in EAB, with most of the difference due to the differential use by white-tailed deer (WAB – 89 vs. EAB – 12) and woodchuck (WAB – 126 vs. EAB - 87).

Although there was much variation between months in the Index of Use (IOC) (Table 2.2), there were no differences between EAB and WAB for any of the seven monthly comparisons ($P \geq 0.340$). Similarly, the average IOC for all months combined did not differ between years for either EAB ($F = 1.445$, df = 18, $P = 0.276$) or WAB ($F = 1.073$, df = 18, $P = 0.430$). With all months combined, the average annual IOC was lower for EAB than WAB only in 2005 ($F = 6.402$, df = 9, $P = 0.035$), but not in 2006 ($P = 0.714$) or 2007 ($P = 0.781$). When both structures were combined, the average annual IOC differed between months ($F = 2.985$, df = 37, $P = 0.020$) with the highest crossing index in May and the lowest in July.

For the culvert, there were 43 crossings during 92 track nights between 23 July 2005 and 19 October 2007, representing five species: ermine (n =25), raccoon (n = 10), mink (n = 6), woodchuck (n =1) and long-tailed weasel (n = 1).

Remote cameras

Track bed cameras

The 35mm camera rotated between the two crossing structures recorded 41 observations of animals between 24 April - 13 Oct 2006 (172 days) and 30 April - 8 Oct 2007 (161 days), representing nine species, including: woodchuck (n =14), white-tailed deer (n = 7), wild turkey (n = 5), eastern cottontail (n = 5), American crow (n = 5), raccoon (n = 2), domestic cat (n =1), opossum (n = 1), and striped skunk (n = 1).

The digital cameras at track beds during the initial month of the 2006 and 2007 field seasons recorded 65 observations of animals, between 24 April - 24 May, 2006 (30 days) and 30 April - 25 May 2007(26 days), representing six species: white-tailed deer (n = 18), woodchuck (n =13), wild turkey (n = 20), domestic cat (n =1), eastern cottontail (n =10), and opossum (n = 3). Of the 18 white-tailed deer recorded approaching the track beds (17 at WAB and 1 at EAB), 13 jumped entirely over the track beds (Fig. 2.7), seven of which paused at the track bed before jumping over. Only three of the 18 deer walked over track beds and none of these deer paused at the beds. One deer walked around the track bed (over two and half minute duration) and another deer stopped abruptly at the track bed and reversed direction. These digital cameras also showed that many of the woodchuck tracks detected along the length of the track beds may be attributed to individuals moving back and forth multiple times, rather than numerous animals.

Stream cameras

Stream cameras recorded 90 animal crossings of six species for both structures combined between 24 May 2006 and 8 October 2007, including: white-tailed deer (n = 53), wild turkey (n = 12), bobcat (n = 9), raccoon (n = 9), woodchuck (n = 6) and domestic cat (n = 1)(Table 2.3). Fifty-seven crossings were recorded along streams at EAB and 33 at WAB with deer representing the majority of these differences (n = 36 at EAB, n = 17 at WAB). When these camera observations are added to the track bed observations, the overall numbers of structure crossings detected for six species increased by 38% in 2006 and 41% in 2007 with bobcat, raccoon, deer, and turkey accounting for the majority of these increases. The stream camera also recorded behavioral images of woodchucks on the west stream side of WAB. Thirteen images of woodchucks entering and exiting two burrows were recorded during the period the stream cameras were in place.

Calibrated white-tailed deer crossing data

Data collected from both the track bed and side slope cameras enabled us to recalculate the number of white-tailed deer crossings. Of the 18 deer detected at the track beds (WAB only), one reversed direction and three walked over the track beds therefore counted as track bed crossings. The remaining 14 were not recorded as crossings. The total period these cameras were in place was 56 days over two years, which calculates to 0.25 deer crossings per day. If detections remained constant and the cameras monitored the track beds for the entire 455 days in which track beds were in place over the three field seasons, the cameras would have detected an additional 114 deer crossings (455 x 0.25) at WAB during our study.

Stream cameras were in place for a total of 276 days during the 2006 and 2007 field seasons. During these periods, 17 additional deer crossings were detected at WAB and 36 at EAB, an average of 0.19 deer crossings (53/276) per day. Applying the 0.19 crossing rate to the 455 days the track beds were in place calculates to an additional 86 deer crossings detected at the streams. Adding the combined the camera data provided an additional 200 deer crossings (114 + 86) over the three years of our study, a 219% increase over the 101 deer crossings detected at the track beds.

DISCUSSION

Track beds and plates as indicators of use

A wide variety of species used ($n \geq 23$) the two crossing structures, reflecting the diverse wildlife community in the area. The mixed hardwood forests adjacent to the roadway, mixed shrub and grass communities and streams within the crossing structures provide a variety of habitats for these wildlife species. Further, the track beds themselves provided nesting habitat for *Peromyscus* and jumping mice.

The large difference in white-tailed deer use between the two crossing structures for all three years (WAB ($n = 89$) and EAB ($n = 12$)) was unexpected considering the juxtaposition of the two structures in relation to the adjacent forest. Although the side slopes of East Airport Brook are steeper and more densely vegetated than along West Airport Brook, relatively flat, grassy areas (10 – 20m wide) occur on the eastern streamsides under each structure, providing relatively unobstructed passageways for deer. Despite the higher number of track bed crossings for WAB, the side slope camera in EAB indicated that deer frequently moved along the stream and game trail rather than across areas with steep vegetated slopes or where track beds occurred. Further, the digital cameras at track beds indicated that deer appeared to hesitate to walk across track beds, frequently jumping entirely over them. The strong contrast of the white marble dust with the surrounding grass and the unnatural surface created by the wood sheets probably contributed to avoidance of track beds by these deer, but may not prevent them from moving through the crossing structures. However, the substantial numbers of deer using stream areas where track beds are absent and jumping over beds suggest that our track beds did not provide accurate counts of deer using the crossing structures.

We did not expect the high number of woodchuck crossings (n = 213) given the ecology of this species. Woodchucks are a semi-fossorial species with generally small home ranges (4.12ha) that are sometimes defended (Merriam 1966, Swihart 1992). Track bed cameras and tracks on the beds indicated that woodchucks using the crossing structures typically moved along the length of track beds rather than across them. We believe that the high number of woodchuck tracks on track beds may be attributed to only a few individuals who regularly moved to and from den sites we found within each structure. This behavior combined with our inability to identify individual animals with cameras or track beds provide inaccurate numbers of woodchucks using the structures.

We suspect that the differences in use between crossing structures for Virginia opossums and domestic cats in 2006 (Table 2.1) are most likely due to single individuals using a particular structure. The disproportionate high use of WAB in 2006 in comparison to similar numbers of opossum crossings for the two structures in 2007 suggest that individual opossums may have used the structures differently during these years. Further, opossum densities are typically low (1 opossum/4ha, McManus 1974) and densities are very likely even lower in southern Vermont where winters are harsh. Similarly, our snow-tracking observations during the 2005/06 and 2006/07 winters (Chapter 3) suggested that a single feral cat used EAB extensively.

Numbers of wild turkey crossings were much higher for EAB in 2006 and 2007. The occurrence of an abandoned agricultural field < 1km northeast of EAB where we frequently observed turkeys feeding probably explain the extensive use of EAB in these two years.

Although there were few crossing observations for river otter and mink, these two species used WAB more frequently than EAB. The perennial stream in WAB provides more suitable habitat for these two semi-aquatic species and the fish prey on which they depend, especially otter (Erlinge 1969, Burgess and Bider 1980). In addition, during our 2005/06 snow-tracking field season, two otter dens were discovered at the pond that serves as the headwaters for the West Airport Brook.

Seasonal behavioral differences may explain the overall IOC differences between months. When comparing the highest (May) and lowest (July) monthly indices, three species make up most of the differences in crossings: woodchuck [May (n = 79), July (n = 20)], wild turkey [May (n = 25), July (n = 5)], and striped skunk [May (n = 9), July (n = 0)]. The high activity of woodchuck in May can possibly be explained by their annual cycle. Woodchucks emerge from hibernation in February and March, when they use their fat stores for nourishment. Fat stores generally become depleted by May, leading to a peak period of foraging during this month (Fall 1971). Woodchucks also display more sociability during spring as well as peak metabolic activity in May (Bailey 1965*a*, Bailey 1965*b*). Increased wild turkey movement during May can possibly be explained by spring flock dispersal and increase in home ranges for adult and yearling females during spring (Ellis and Lewis 1967, Badyaev et al. 1996). High amounts of striped skunk movements in May can possibly be explained by increases of home ranges for males searching for mates and both sexes increased foraging in spring (Lariviere and Messier 1997, Bixler and Gittleman 2000). After May, average IOC values continued to decline through July after which IOC values began to increase again, presumably with increased foraging activity in late summer and fall.

The high use of the culvert by ermine relative to the crossing structures in our study was probably the result of the culvert's small, confining space (openness ratio = 0.02m). Clevenger et al. (2001*a*) reported that ermine prefer culverts with low openness ratios and low through-culvert visibility. This low openness ratio for ermine contrasts greatly with the larger openness ratios recommended for mule deer (> 0.6) and Florida panther (*Felis concolor coryi*) (0.92) (Reed et al. 1982, Reed et al. 1975, Foster and Humphrey 1995). Further, the limited need by ermine for through visibility in a culvert may stem from their hunting strategy that requires travel through burrows and runway systems of rodents (King 1989).

Cameras as indicators of use

Although the 35mm camera used to monitor track beds recorded only one species (American crow) not detected by the track beds, this camera provided us few useful data on numbers of crossings through the structures. This camera was frequently inoperable, thereby missing many of the taxa that moved through the structures, and also failing to record any species smaller than domestic cats. In contrast to the limited data provided by the 35mm cameras, the digital cameras used at track beds provided us the ability to more accurately assess the frequency of structure use by deer and woodchucks. The ability of these digital cameras to record multiple frames over a short time period provided important information on deer and woodchuck behavior at track beds.

Although stream cameras recorded the occurrence of much fewer taxa (n = 6) than track beds (n = 26) for the monitoring periods that both were operational, these cameras provided important information on animal crossings through the structures in areas not monitored by track beds (Table 2.3). These camera observations were critical for recording the use of structures by bobcats and several other species, especially through EAB. These camera data also underscore the importance of using cameras in areas within structures that cannot be monitored by track beds.

We believe the higher numbers of crossings detected by stream cameras in EAB (n = 67) compared to WAB (n = 33) is related to several factors. Areas monitored by our camera in EAB included a distinct game trail that was frequently used for crossings. There was no obvious game trail within WAB. The occurrence of this game trail in EAB may have reduced the effects of the relatively steep, densely vegetated slopes on animal movements within this structure. Further, the camera within EAB frequently recorded animals using the intermittent stream channel to move through the structure. In contrast, we never recorded any animals moving through the perennial stream channel in WAB. The extensive riprap areas in WAB where track beds could not be constructed may have also discouraged animals moving through these sections of this structure. There was no riprap within EAB.

Effectiveness of track beds and remote cameras

Track beds are often difficult to construct and maintain. Using marble dust for the track bed substrate requires relatively flat areas free of woody vegetation and minimal exposure to disturbances. We first used sand for our tracking substrate. However, it was too coarse and lacked resolution for identifying tracks. Next, we used marble dust as recommended by Yanes et al. (1995). Although the marble dust provided excellent track resolution, the unevenness of the ground combined with vegetation growing through the dust rendered sections of the track bed inoperable and required extensive maintenance. Incorporating the OSB plywood as a foundation for the marble dust provided us a stable substrate for the track beds and eliminated vegetation growth in the beds.

Disturbance by weather, livestock or human activity is a limiting factor for track beds, frequently making track beds inoperable and requiring frequent maintenance (Rodriguez et al. 1996, Rodriguez et al. 1997, Norman and Finegan 1998, Veenbaas and Brandjes 1999). In our study, track beds were disturbed (inoperable) by rain for 21 of the 130 days we checked them during three field seasons. Although placement of track beds within culverts (Hunt et al. 1987, Yanes et al. 1995, Rodriguez et al. 1996) helps to reduce disturbance by rainfall, stormwater flow through culverts typically requires that track beds be reconstructed. In our study, we frequently reconditioned the sooted track plates within the single culvert following rainfall events over three field seasons.

Similar to other studies (Yanes et al. 1995, Rodriquez et al. 1996, Mata et al. 2004), we found that track beds are effective for recording a wide variety of vertebrate taxa moving through a crossing structure. However, we were not always able to identify to the species level for both medium- and small-sized mammals. Similarly, Rodriguez et al. (1996) reported difficulty in reliably identifying small mammals to species using track beds at 17 non-wildlife passages which were primarily culverts. Mata et al. (2004) also reported difficulty in identifying species of hare and rabbit, small mustelids, felids and canids to species in their track bed study in Spain.

Although our track beds recorded large numbers of woodchuck tracks, track bed cameras indicated that woodchucks typically moved along the length of track beds rather than across them. Similarly, we recorded relatively few actual crossings through structures in our small mammal mark/recapture study (Chapter 4). Thus, the moderately high numbers of small mammal tracks we recorded on track beds were most likely due to daily home range movements within structures rather than crossings through them, as also reported by Mata et al. (2004). These types of behaviors within structures confound using presence/absence data from track beds as a measure of crossing rate as reported by Rodriguez et al. (1996, 1997). We overcame this limitation for the culvert we monitored with sooted track plates by placing a plate at both ends of the culvert. A crossing was only recorded if the tracks of a particular species were recorded on both plates and moving in the same direction. Ng et al. (2004) reported using three sets of track beds within single structures to confirm actual passage through structures. Cameras can also reduce this limitation of track beds for determining numbers of crossings by recording behaviors at track beds.

The cameras we used at track beds were critical for recording behaviors at track beds and evaluating the effectiveness of track beds for recording crossings through the structures. Without these camera observations, we would not have detected deer jumping over track beds, thereby under-reporting the numbers of deer crossings. Likewise, without cameras, we would not have identified that the frequent movements of woodchucks along the track beds rather than crossing through structures. The recording of behaviors at track beds required a camera with the capacity to record multiple images/trigger over a short time period (10 images/trigger at two frames/sec in our study).

Several studies report advantages of using cameras for monitoring structures compared to track beds, including: ease of use, less prone to disturbance factors such as rain, flexibility of placement, low cost of maintenance, high equipment reliability, and increased accuracy of species identification (Norman and Finegan 1998, Mata et al. 2004, Ng et al. 2004, Silveira et al. 2003). However, cameras are most effective for recording medium- and large-sized vertebrates within structures and probably miss many small-sized animals. Similarly, Norman and Finegan (1998) reported that multiple cameras mounted within three highway underpasses were not able to detect small reptiles, amphibians and mammals. The initial costs for some cameras, especially programmable units like the Reconyx cameras we used, are relatively high; however, they can be used for multiple years. Several crossing structure studies report problems with vandalism and theft of cameras (Norman and Finegan 1998, Austin and Garland 2001, Ng et al. 2004). Although cameras have the potential to recognize some individual animals (Silveira et al. 2003), it is typically difficult to determine numbers of individual animals moving through a crossing structure. Mark/recapture or telemetry studies are needed to determine actual numbers of animals using a crossing structure.

MANAGEMENT IMPLICATIONS

Increasingly, wildlife crossing structures are being used in an attempt to reduce the impacts of roads on wildlife and provide safer roads for the driving public (Hardy et al. 2004). A key component in developing optimal crossing structures is the ability to accurately monitor the effectiveness of the structures. However, only a limited number of projects have implemented monitoring programs into their design and results of monitoring frequently go unreported (Romin and Bissonette 1996*b*, Clevenger and Waltho 2005, Cramer and Bissonette 2005,). Monitoring should become a component of crossing structure design. Refining and sharing of useful techniques can assist engineers in developing more effective crossing structures and study designs for monitoring.

While both track beds and remote cameras are important tools for monitoring use of crossing structures by wildlife, they only provide an index to crossing structure use because individuals typically cannot be identified using these two monitoring techniques. If the objective of a study is to document frequency of structure use by individuals, mark/recapture and telemetry monitoring may be necessary. Further, measuring the effectiveness of a structure is limited by the difficulty of monitoring crossings or avoidance of the road by animals in areas away from crossing structures. However, winter snow-tracking provides a monitoring tool to overcome this limitation for some species during the times of the year when suitable snow conditions occur (Chapter 3). Although not possible in our study, it is also critical to conduct pre-construction monitoring using telemetry and snow-tracking to better evaluate how construction of the roadway may have affected the behaviors of animals.

Results from this study indicated that rip rapped areas do not provide suitable habitat for a wide variety of wildlife moving through crossing structures and should be minimized as much as possible in crossing structure designs. Additionally, natural vegetation within structures should be maintained to the maximum extent possible during structure construction. Existing game trails need to be identified prior to roadway construction and incorporated in crossing structure placement whenever possible. Small diameter culverts with low openness ratios do not provide effective crossing structures for many mammal species in our study area, but were used preferentially by ermine. Finally, effective fencing to funnel animals into the crossing structure would profoundly enhance the efficacy of the crossing structures.

Figure 2.1. West Airport Brook (WAB) crossing structure showing rip rap slope and white track bed.

Figure 2.2. Track beds constructed from 1.2m x 1.2m sheets of 1.2cm-thick Oriented Strand Board (OSB) covered with marble dust.

Figure 2.3. Track plate and recorded tracks.

Figure 2.4. 35mm camera used to monitor passage structures.

Figure 2.5. Reconyx digital infrared camera used to monitor passage structures.

Figure 2.6. Reconyx camera positioned to monitor a streambed where track beds could not be used.

Figure 2.7. Deer leaping over track bed.

Table 2.1. Number of wildlife track bed crossings at East Airport Brook (EAB) and West Airport Brook (WAB) crossing structures, Bennington, VT. 2005 - 2007

	2005 (99)[a]			2006 (141)			2007 (109)			Totals (349)	
Species	EAB	WAB	*p* [b]	EAB	WAB	*p*	EAB	WAB	*p*	EAB	WAB
White-tailed deer (*Odeocoileus virginianus*)	4	27	< 0.000	0	35	< 0.000	8	27	< 0.000	12	89
Bobcat (*Lynx rufus*)	1			2	3			1		3	4
Felidae		4								0	4
Coyote (*Canis latrans*)	2	1		1	1			3		3	5
Canidae				1	1			1		1	2
Gray fox (*Urocyon cinereoargenteus*)	1	1								1	1
Fisher (*Martes pennanti*)		4								0	4
River otter (*Lontra canadensis*)		2								0	2
Mink (*Mustela vison*)		2		1	3		1			2	5
Long-tailed weasel (*Mustela frenata*)				3			1			4	0
Ermine (*Mustela erminae*)					1					0	1
Striped skunk (*Mephitis mephitis*)				1			8	1		9	1
Raccoon (*Procyon lotor*)	3	5		9	11	0.655	2	2		14	18
Porcupine (*Erithizon dorsatum*)		1								0	1
Virginia opossum (*Didelphis virginiana*)				1	12	0.002	6	8	0.593	7	20
Eastern cottontail (*Sylvilagus floridanus*)	1	2		8	3	0.132	3			12	5
Woodchuck (*Marmota monax*)	31	22	0.216	35	60	0.010	21	44	0.004	87	126
Gray squirrel (*Sciurus carolinensis*)		2		5	6	0.763	11	7	0.346	16	15
Red squirrel (*Tamiasciurus hudsonicus*)							1	2		1	2
Eastern chipmunk (*Tamias striatus*)				2	3		4	3		6	6
Muskrat (*Ondatra zibethicus*)	3	3			2					3	5

Continued Next Page

Jumping mouse (meadow or woodland)		9		2	1					2	10
Peromyscus (white footed or deer mouse)				8	19	0.034	3	11	0.033	11	30
Domestic cat (*Felis domesticus*)	12			36	3	< 0.000	3			51	3
Medium mammal		4		8	3	0.132	21	15	0.317	29	22
Small mammal	7	27	< 0.000	7	1		13	4	0.029	27	32
Wild turkey (*Meleagris gallopavo*)	10	10	1.000	19	1	< 0.000	22	6	0.003	51	17
Common garter snake (*Thamnophis sirtalis*)		1								0	1
Snapping turtle (*Chelydra s. serpentina*)		1								0	1
Ranidae (frog)		1			1					0	2
Totals	75	129	< 0.000	149	170	0.240	128	135	0.666	352	434

[a] = number track nights, [b] = *p* for chi-square goodness-of-fit test

Table 2.2. Index of use for wildlife track bed crossings at East Airport Brook (EAB) and West Airport Brook (WAB) crossing structures, Bennington, VT, 2005 – 2007. Index = # recorded crossings/# track nights.

		Month							
Structure		April (4,14,3)[a]	May (30,17,18)	June (31,15,18)	July (22,22,23)	August (12,28,20)	September (0,29,20)[b]	October (0,16,7)	Yearly average
East Airport Brook	2005	1.250	0.900	0.677	0.727	0.500	n/a	n/a	0.758
	2006	1.000	1.824	0.467	0.955	1.143	1.138	0.688	1.057
	2007	3.333	3.000	1.000	0.130	0.600	0.750	2.286	1.174
	Averages	1.861	1.908	0.715	0.604	0.748	0.944	1.487	0.996
West Airport Brook	2005	2.000	1.800	0.807	1.318	1.250	n/a	n/a	1.323
	2006	0.714	1.177	0.600	0.864	1.679	1.586	1.188	1.206
	2007	2.000	2.667	1.444	0.652	0.550	0.800	1.857	1.239
	Averages	1.571	1.881	0.950	0.945	1.160	1.193	1.523	1.256
Overall	2005	3.250	2.700	1.484	2.045	1.750	n/a	n/a	1.040
	2006	1.714	3.001	1.067	1.819	2.822	2.724	0.938	1.131
	2007	5.333	5.667	2.444	0.782	1.150	1.550	4.143	2.413
	Averages	3.432	3.789	1.665	1.549	1.907	2.137	2.541	1.528
ANOVA - *P*		0.752	0.973	0.473	0.340	0.345	0.627	0.971	0.114

. [a] = number track nights for (2005,2006,2007), [b] = no data collected September-October 2005

Table 2.3. Numbers of wildlife crossings by six species detected by track beds and cameras in two wildlife crossing structures, Bennington, VT.

	2006 (128 track nights)						**2007** (84 track nights)					
	East Airport Brook			West Airport Brook			East Airport Brook			West Airport Brook		
Species	Track bed	Camera	Total	Track bed	Camera	Total	Track bed	Camera	Total	Track bed	Camera	Total
White-tailed deer	0	21	21	34	16	49	8	15	23	25	1	26
Woodchuck	10	1	11	48	4	49	8	1	9	22	0	22
Raccoon	5	2	7	4	2	7	1	3	4	0	2	2
Bobcat	0	0	0	0	1	1	0	6	6	0	2	2
Wild turkey	11	7	18	1	0	1	13	0	13	6	5	11
Domestic cat	34	1	35	3	0	3	3	0	3	0	0	0
Totals	60	32	92	90	23	113	33	25	58	53	10	63

CHAPTER 3.

APPLYING A CONCEPTUAL MODEL OF MOVEMENT TO SNOW-TRACKING AS A MEANS TO EVALUATE EFFECTIVENESS OF WILDLIFE CROSSING STRUCTURES

INTRODUCTION

The barrier effect created by linear infrastructures such as roads can lead to isolation of wildlife populations and disruption of gene flow and metapopulation dynamics (Andrews 1990; Bennett 1991; De Santo & Smith 1993; Yanes et al. 1995). Attempts have been made to increase permeability of roads to animals through use of crossing structures (Clevenger & Waltho 2000). Only a few studies have attempted to quantify the efficacy of these structures. The scope of most monitoring studies is generally narrow, focusing primarily on larger carnivores and ungulates, focusing almost exclusively on use of the structures (Forman et al. 2003).

Even with a broad approach to monitoring, it is hard to define criteria for success of a crossing structure project without a clear set of mitigation objectives. Crossing structures are frequently installed with a broad or poorly defined set of objectives (Hardy et al. 2004). If the primary purpose is preventing animal-vehicle collisions (i.e. human safety) the most direct measure of success would be a reduction in the number of collisions or the risk of collisions. Where wildlife conservation is the primary objective of a project, long-term measures of population viability of target species are the only direct measures of success (Sanderson et al. 2002). Data on the movement of wildlife species through a crossing structure is, at best, only an indirect and partial measure of the success of a mitigation project. To interpret patterns of use of structures, a point of reference is needed. For example, differences in total crossing counts for a species between two structures might simply reflect differences in population densities of that species at the two locations (Forman et al. 2003). Ideally, comparisons should be drawn between pre- and post-construction movements of target species in the area and include an evaluation of the extent to which the roadway (including crossing structures) inhibits wildlife movement through the area. When pre-construction surveys are not available, the only available standard of comparison is *non-use* of structures.

Movements of animals in the vicinity of roads and crossing structures can range from movements parallel to the road to various kinds of crossings to complete avoidance of the road (Fig. 3.1). To create a framework for assessing both "use" and "non-use" movements, we developed a conceptual model (Fig. 3.1). Crossings through structures are the most commonly detected movements in conventional monitoring (Fig. 3.1*e,f*), but the same species using the structures might also cross via the road surface (Fig. 3.1*a,b*). Some animals actively avoid road corridors (Fig. 3.1*h*). The 12 movements illustrated in Fig. 3.1 define the scope of monitoring needed to assess relative use and non-use of crossing structures.

Few monitoring techniques have the ability to detect the full range of movement types shown in Fig. 3.1. Track beds and cameras are usually placed at or within the crossing structures, limiting their detections to use of the structures (Fig. 3.1 *e, f* and *m*). Radio telemetry can be used to detect broad scale animal movements across the landscape shown in Fig. 3.1 (Brody & Pelton 1989; Lovallo & Anderson 1996), and it can be used to assess demographic differences in crossing frequency, such as whether males or females are more likely to cross roads (McCoy 2005). Dodd and colleagues (2007) used GPS telemetry to examine Rocky Mountain Elk (*Cervus elaphus nelsoni*) permeability across a 30km stretch of road in Arizona. However, telemetry cannot be used to distinguish finer scaled movements, such as crossings via the structures vs. via the road. In addition, it can be invasive, time consuming, expensive and prone to location error (Weckerly & Ricca 2000; Fedak 2002). Less expensive, non-invasive monitoring methods such as snow-tracking are gaining popularity in wildlife research (Schauster et al. 2002).

For collecting information about dispersal, individual identity, or social affiliations snow-tracking cannot replace telemetry (Alexander et al. 2005*a*). However, snow-tracking can document presence and fine-scaled movements of species in relation to roads and mitigation structures (Clevenger et al. 2002). While snow-tracking cannot provide absolute numbers of individuals using crossing structures or roads, it can provide relative rates for different types of movement both near and far from roads (Huijser & Bergers 2000). Fore-tracking and back-tracking of trails encountered provides detailed descriptions of movements of animals within their home ranges. This is especially effective when monitoring effects of discrete landscape features, such as road corridors, fences, and crossing structures. Ideally, efficacy of structures should be assessed through a combination of methods, including telemetry, cameras, track beds and snow-tracking. When funding or personnel are limiting, snow-tracking is perhaps an ideal single-method monitoring approach.

Here, we demonstrate a snow-tracking based method of evaluating use and non-use of crossing structures along a highway in Bennington, VT. With the conceptual model of movement as our framework for analysis, the objectives of our study were to 1) assess the degree of permeability of the road including the crossing structures, and 2) determine relative use of the structures versus use of the road for crossing.

METHODS

We conducted our research during the winters of 2005-06 and 2006-07 in Bennington, Vermont along a 1.9km stretch of highway that encompassed three wildlife crossing structures, two extended bridges and one large culvert (Fig. 1.2). The average daily traffic (ADT) for Highway 279 was 4,674 and 4,882 for the 2005-06 and 2006-07 winter field seasons respectively. We exclude the culvert from our analyses because we detected no animal crossings through it in our snow-tracking seasons.

We laid out a 39.5ha grid for snow-tracking consisting of four transects parallel and twelve perpendicular to the highway (Fig. 3.2). The grid extends 500m to the east of EAB and 500m to the west of WAB. We placed two of the parallel transects on each side of the highway, one along each highway edge, and the other two 100m into the forest on either side of the road. The 12 perpendicular transects start at the road's edge and extend to the farther parallel transect, 100m into the forest. Taken together, the transects allow us to detect animal movements both near and far from the road as well as at key barriers such as fencing.

We conducted snow-tracking sessions between 24 and 72 hours after snowfalls of >1in (1.3cm) as reported by the National Weather Service station in Bennington. We used Palm Pilots with cybertracker software integrated with GPS to record: species, direction of movement, markings (e.g. – scat, scent marking), locations of highway crossings, weather, number of days since last snowfall, snow depth, date and time. In addition, we measured tracks, gaits and gait pattern to confirm uncertain species identifications. Due to its size, we were unable to walk the entire grid in a single day. To distribute our search effort amongst tracking sessions, we varied our search pattern through the grid.

When we encountered animal tracks along any of the transects, we backtracked and foretracked using GPS as long as they were discernible up to 200m from the roadway edge. Crossing points were recorded with the GPS units where the tracks crossed over the road or through a structure. We tracked all species weasel size or larger with the exception of white-tailed deer (*Odocoileus virginianus*) and domestic cat (*Felis domesticus*). For deer, we recorded only road and structure crossings, due to the volume of tracks and the difficulty in differentiating individual trails. We did not track domestic cat due to lack of conservation concern for the species.

Snow plowing typically disturbs the snow pack approximately 5m to either side of the highway. Thus, we checked the areas just beyond the "snowplow zone" carefully to capture tracks heading towards the highway, attempting to match tracks on either side of the roadway for potential road crossings. When matched tracks were not found, the tracks were marked and classified as a probable crossing but were not included in the analyses.

We imported all GPS points into ArcGIS 9.1 and overlaid the points onto orthophoto images of our study area downloaded from Vermont's GIS database, VCGI, Waterbury, VT (Fig. 1.2). We grouped all GPS points into sets of tracks. We defined a set of tracks as all of the GPS points collected for an animal trail from starting point to an end point. We used Hawth's Analysis Tool (Beyer 2004) to connect points and identify direction of movement of each set of tracks. Each set of tracks was examined and classified independently by 3 observers (M. Bellis, N. Charney and D. Paulson) by identifying the predominant pattern for each set. Final classifications into one of the 11 movement categories (Fig. 3.1) were determined by consensus among the observers. Any set of tracks that contained too few tracks or did not have a distinguishable pattern was classified as not identifiable (Table 3.1, NI). Most non-identifiable trails were too short to define a trajectory of movement, consisting of just 2-3 tracks.

We used the frequencies for each movement type to analyze: 1) permeability of the roadway, 2) relative use of the structures vs. the road for crossing and 3) effectiveness of lead fencing for funneling animals through crossing structures. Because we cannot distinguish individuals with this method, we focus on the relative frequencies of different movement types. Based on home range sizes and natural history of the species we detected (DeGraaf & Yamasaki 2001), we expect that the movement data represents activities of at least 2 individuals per species, and many more individuals for coyote (*Canis latrans*) and white-tailed deer.

Permeability of roadway

According to Cramer and Bisonette (2005) a permeable landscape feature is one that allows free daily movement of a species across its home range. The four species (coyote, bobcat (*Lynx rufus*), mink (*Mustela vison*) and fisher (*Martes pennanti*) which comprise 88% of our movement data, all have home ranges (from 3km^2 for mink to 52km^2 for coyote) that would require them to move across the roadway because core habitat on either side of the road is limited (DeGraaf & Yamasaki 2001). We evaluated permeability by using the conceptual model in Figure 3.1 to create a metric that provides a general determination of whether the roadway imposed a barrier to movements. In our analysis we used metrics versus statistical formulas since we cannot assume each set of tracks are independent of one another and therefore violates an assumption necessary for most statistical tests.

Following Dodd et al. (2007), we considered any tracks detected in our grid as an approach to the roadway. When analyzing permeability, constrained movement or reduced permeability, should result in fewer crossings than non-crossing movements, i.e. movements along or away from the road. Crossings are movements *a, c, e, f, l* and non-crossing movements are *b, d, g, h, i, k* (Fig. 3.1). Our metric is simply the number of successful crossings divided by the number of non-crossing movements [Σ (*a,c,e,f,l*) / Σ (*b,d,g,h,i,k*)]. Any value >1 suggests the roadway is a permeable landscape feature and a value <1 suggests the roadway is non-permeable feature. The greater the value above 1 suggests a higher degree of permeability and vice versa for values less than 1. In cases where the denominator is 0 (no movements along or away) we assigned a metric value equal to the numerator (across roadway). In cases where the numerator is 0 we assigned a metric value of 0. For this analysis we used combined data from both years since we lacked data for several species in one of the two field seasons. We evaluated the permeability of the roadway both at the species level and overall.

Relative use of crossing structures vs. road

Next, we analyzed whether crossings were more frequent through the structure than across the road surface. Each road crossing puts animals and humans at risk via animal-vehicle collision. Thus, a successful mitigation project should have more structure crossings (Fig. 3.1*e, f, l*) than successful or attempted road crossings (Fig. 3.1*a, b, c*). We evaluated differences in use of the structures vs. roadway by using the metric [Σ (*e,f,l)* / Σ (*a,b,c*)] which addresses both public safety and the need to facilitate movements for wildlife. For this metric, a higher number is desired since it represents a higher proportion of animals using the structures versus being at risk for collision. Values = 1 represent an equal number of structure vs. road crossings, > 1 a higher number of structure crossings and < 1 a higher number of road crossings. We excluded gray fox from this analysis since no road or structure crossings were detected for this species.

RESULTS

We recorded a total of 162 sets of animal tracks over 24 snow-tracking surveys representing a total of 47 track nights between 11 December 2005 and 25 February 2007. Fifteen surveys representing 30 track nights were conducted during the 2005-06 field season and nine surveys representing 17 track nights were conducted during the 2006-07 field season. We recorded sets of tracks for the following species: coyote, bobcat, mink, fisher, long-tailed weasel (*Mustela frenata*), river otter (*Lontra canadensis*), gray fox (*Urocyon cinereoargenteus*) and raccoon (*Procyon lotor*) (Table 3.1). For white-tailed deer and domestic cat, we only recorded road and passage crossings.

We were able to classify a total of 117 sets of tracks into movement categories (Table 3.1). Movement *a*, (successful movement across the roadway) (n = 39), was the most commonly recorded movement followed by *f* (direct movement through crossing structure) (n = 25) and *k* (movement parallel to roadway) (n = 17) (Table 3.1). No animals used the culvert for passage (Fig. 3.1, *l*) during our two winter field seasons, though we detected regular crossings through the culvert by five species during our summer field seasons. No animals we tracked were hit by vehicles (Fig. 3.1, *b*).

Permeability of the roadway

Using our permeability metric we derived an overall permeability value of 1.66 (73/44) (Table 3.2) for the two crossing structures across both years. We calculated value >1, denoting permeability, for six of the eight species we snow-tracked including; coyote (1.39), bobcat (1.83), mink (9), long-tailed weasel (4), river otter (3) and raccoon (3). Values <1, denoting limited permeability, were calculated for two species, including fisher (.57) and gray fox (0).

Relative use of crossing structures vs. road for movement

A further measure of the effectiveness of the crossing structures is a comparison of the frequency of crossings through structures versus over the road surface. We detected 30 structure and 42 road crossings during the 2005-06 field season and 38 structure and 17 road crossings during the 2006-07 field season. All nine of the species detected in this portion of the study used the structures, and seven of the nine species crossed via the road (Table 3.3). The two species that only crossed using the structures were mink and otter, species that typically travel along streams like the ones in these structures. Four species used the crossing structures in 2006-07 that were not recorded in 2005-06: bobcat, long-tailed weasel, domestic cat and raccoon. White-tailed deer had the most frequent number of structure crossings in both 2005-06 (n = 12) and 2006-07 (n = 21). Coyote had the most frequent number of road crossings in both 2005-06 (n = 23) and 2006-07 (n = 8).

DISCUSSION

Snow-tracking provided a useful approach to measuring the effectiveness of mitigation crossing structures along the Bennington Bypass by allowing us to compare use with non-use of the structures. Overall, we found that the Bypass is a relatively permeable landscape feature to most of the nine species detected. Once they were within our study area (100m from the road's edge), most species were at least as likely to cross the road (over the road surface or through a structure) as they were to move away from it or along it. The crossing structures are used frequently and by most species. However, this finding is tempered by continued crossings via the road, putting animals in danger of collision. Several species, including river otter, mink and white-tailed deer, are using the crossing structures more often than expected by chance. Deer, in particular, increased their use of the crossing structures over the course of the study. Bobcat and coyote, however, do not preferentially cross using the structures. Instead, they appear to be crossing at junctions between the road and pre-existing game trails at least as frequently as they use the crossing structures.

Permeability of the roadway

Several factors other than the presence of crossing structures may contribute to the degree of permeability we found along Bennington Bypass. Several species that we tracked adapt well to altered landscapes. Coyote and bobcat, for example, have been well documented as urban adaptive animals (Grinder & Krausman 2001; Tigas et al. 2002). Likewise, raccoon also readily use roadside areas (Prange et al. 2003).

Another factor may be the lack of barrier fencing bordering the roadway. The majority of the Bypass is lined with 1.2m right of way fencing, which is easily crossed by most species based on our findings here and in remote camera images taken in the summer season. Tall, lead fencing (2.4m) only extends approximately 65m on either side of the crossing structures. Mitigation fencing has been found to minimize vehicle-animals collisions by keeping wildlife off the road, but only if it is both high enough and extends along major portions of a highway's length (Clevenger et al. 2001*b*).

The Bennington Bypass crossing structures may be important in maintaining permeability for a few particular species. Semi-aquatic species such as mink and otter benefit from the placement of the structures along this riparian area (Melquist & Hornocker 1983). Mink and otter forage along streams and ponds for fish and invertebrates and can coexist within the same habitat (Erlinge 1969; Burgess & Bider 1980; Bonesi & Macdonald 2004). The stream may serve as an important movement corridor for otter in this area, given that two dens were found at a pond serving as headwaters for West Airport Brook. West Airport Brook flows into the Walloomsac River, a river abundant with fish. Places where streams cross roads are often handled with culverts and viaducts, which disrupt stream flow and do not protect streamside habitat important for wildlife crossings (Jackson 2004).Thus, the size and openness of the crossing structures along Bennington Bypass renders them of potential importance to semiaquatic species.

Relative use of crossing structures and roadway for movement

Direct comparisons of our findings are hampered by a paucity of studies addressing both use and non-use of structures. Using a combination of monitoring techniques, Singleton and colleagues (1999) detected only 2 structure crossings out of 37 roadway crossings along 30 miles of road in Snoqualmie Pass, WA. Their study monitored 13 species ranging in size from deer mice (*Peromyscus sp.*) to mule deer (*Odocoileus hemionus*). Our ratio of structure crossings to road crossings (nearly 2:1) far exceeds that found by Singleton and colleagues. None of their crossing structures were designed as wildlife crossings, and the highway they monitored is an interstate with more than 5 times the traffic volume (24,400 vehicles/day) at the Bennington Bypass. Using both telemetry and track bed data, Cain and colleagues (2003) found that bobcat frequently crossed a 32.3km section of highway in south Texas leading to 25 road killed bobcat over two years. They also found that bobcat used the 18 crossing structures located throughout the highway (five of which were modified for felid use) and exhibited a preference for structures with higher openness ratios. In both instances, the availability of preferred bobcat habitat adjacent to the structure entrances and road crossing area was the primary characteristic that influenced their crossings in these areas.

The large size of the Bennington Bypass appears to be conducive for movement of medium and large mammals. Only 7% of animals (n = 2) that encountered the crossing structures moved away from them. The structures appear to provide favorable habitat for many species due to the presence of streams within the two crossing structures. Species such as white-tailed deer, coyote, Virginia opossum (*Didelphis virginiana*) and raccoon use streams as movement corridors (Spackman & Hughes 1995; Allen et al. 1985). In addition, the structures far exceed the openness ratio (x-section/length in meters; Reed & Ward 1985) recommended for larger species (Foster & Humphrey 1995; Jackson & Griffin 2000; Gordon & Anderson 2004). By contrast, the large size of the structures may inhibit movement of smaller mammals (Rodriguez et al. 1996; Clevenger & Waltho 1999; Foresman 2004*a*, Foresman 2004*b*). Other experiments are addressing this issue through management of cover for small mammals in the openings. Snowtracking is not able to capture movements of these species. In addition to their large size, they span riparian areas, thereby encompassing the some of the most diverse, dynamic and complex biophysical habitats in terrestrial zones (Naiman et al. 1993).

Deer in our study showed an almost three fold increase in use of the crossing structures between the first and second years of our study (Table 3.3). There are several possible explanations for this increase: a) natural shifts in populations, b) shifts in geographical distribution, c) habituation by wildlife to the crossing structures, or d) improved vegetative cover over time. Our findings are consistent with several other studies that reported an increase in use of crossing structures over time, suggesting there is an initial acclimation period (Land & Lotz 1996; Clevenger & Waltho 2004; Baofa et al. 2006). Clevenger and Waltho (2004) found a more than fivefold increase in use by ungulates, especially deer, over a 5-year period. Monitoring of the Bennington Bypass over a longer period is needed to determine whether the increase in deer use of the structures is due to habituation or to unrelated population shifts.

Two species, coyote and bobcat, are noteworthy for their low use of the crossing structures. Sixty nine percent of all road crossings were by coyote and bobcat. Detections of coyotes along the road remained constant between 2005/06 (79%) and 2006/07 (80%). While bobcat showed a decrease in use of the road from 2005-06 (100%) to 2006-07 (57%), the shift in use was almost certainly due to the presence of a road killed deer heavily fed on by bobcat in the WAB structure for all of the 2006-07 field season. Most roadway crossings occurred in areas that lacked steep slopes and guardrails and where forest cover came closest to the road edge. We suggest that the primary reason these species used the road for crossings is their association with game trails that intersect the roadway away from the crossing structures. Thirteen coyote trails followed an unused logging road at the far southwest corner of our grid and was heavily scent marked throughout its length. Scent marking may indicate the presence of coyote packs in the area since lone coyotes do not scent mark (Barrette & Messier 1980).

Bobcat used two game trails, one trail used by the coyote (n = 4) and a second game trail approximately 250m to the east of the WAB crossing structure (n = 7). Bobcat use of the southwest game trail may be attributed to the limited open space that bobcat need to cross the road in this area. The distance from the forest edge on the south side to the north side of the roadway in this area (40m) is shorter than most areas along the Bypass. The location of this game trail is consistent with findings by Cain et al. (2003), who found that bobcat crossed roads most frequently in areas where distances between dense vegetation was shortest. The second game trail used by bobcat followed a footpath on the north side and along a stone wall on the south side of the roadway. Bobcat showed signs of foraging along the wall, a typical habitat for numerous small mammal species (Fahrig & Merriam 1985). After we identified these game trails in the 2005/2006 season, we confirmed the year-round use of these trails by both bobcat and coyote through motion-sensing cameras placed along both trails in the summer. If a goal of the crossing structures was to mitigate impacts of the road on these species, pre-construction surveys of their movements could have been used to identify these game trails as important sites for mitigation.

Another factor that likely influenced coyote road crossings here and elsewhere is the abundance of prey in the right-of-way. We also found numerous subnivean tunnels in the road right-of-way, a likely indication of meadow voles (Madison et al. 1984). While tracking in this area, we frequently noted signs of active coyote foraging, e.g. pouncing and digging. Thus, the right-of-way represents a typical foraging area for coyotes, increasing the probability that they would cross the road rather than use the structures.

Potential Avoider Species

Several species may be avoiding the road area altogether, or in the case of fisher, generally avoiding the road or structures. More fisher tracks were detected moving across and along or away from the roadway. Four of the 14 fisher tracks that we detected went across the road or through the structures, four sets were parallel to and three sets moved away from the roadway (an additional 3 were unidentifiable). The parallel tracks were detected in forested areas away from the road. This can possibly be explained by fisher preference for foraging in forested habitat and avoidance of open areas in winter (Powell 1994). The riparian areas within the structures would generally be favorable habitat for fisher but the lack of canopy cover in these areas may inhibit their movement (Witmer et al. 1998). The limited movement of fisher across the road or structures illustrates the importance of identifying target species and their required habitat when designing wildlife crossings.

It was unexpected that that few gray fox and no red fox were detected in the area since the habitat is suitable and they are both generally urban adaptive animals (Doncaster & Macdonald 1991; Harrison 1997). The habitat in the area adjacent to the Bypass is suitable for both species since a variety of habitats ranging from dense forests to pastures exist in the area. In addition, both species are known to coexist in areas with low densities of coyote but avoid areas with high coyote densities (Voigt & Earle 1983; Chamberlain & Leopold 2005; Farias et al. 2005). Coyote densities may be high in the area based on the high number of coyote tracks detected throughout the study area.

Two species that may have occupied this area prior to construction are black bear (*Ursus americanus*) and moose (*Alces alces*). The presence of a forest dominated landscape and wetlands in the area create favorable habitat for both species (DeVos 1958; Samson & Huot 1998). Anecdotal evidence of their presence was provided during discussions with local landowners and the area game warden. In addition, we identified several bear clawed beech trees in the area, a sign of black bear foraging (Faison & Houston 2004). These observations may support findings by Brody & Pelton (1989) who found that bear attraction or avoidance of roads depends on the amount of threat perceived by them. In public parks where vehicles drive slowly and humans are seen as a food source, bears are attracted to roads, while in areas with heavy traffic roads may be perceived as a threat. It is unknown whether black bear will repopulate the Bypass area. Clevenger and Waltho (2004) observed a slight increase of crossing structure use by black bears over a five-year period in Banff, Canada.

Using Metrics to Evaluate Effectiveness of Mitigation

Using the conceptual model in Figure 3.1 we created metrics for determining success based on various potential project objectives (Bellis et al. 2007). For purposes of evaluating the effectiveness of the expanded bridges based on our snow tracking data we use three metrics representing different mitigation objectives (Table 3.4).

1) *Public Safety Only*

If the objective of a project is solely to prevent animal-vehicle collisions then the following metric would be appropriate.

Σ (a, b, c)

In cases where the number of collisions that can be tolerated is low (moose) the criteria for success would be set at a very low number. In this case continued use of the roadway by wildlife (movement types a & c) or ongoing roadkill (b-type movement) would indicate that the mitigation has not been successful. Where the objective is to reduce but not necessarily eliminate roadkill (amphibians on a causeway through extensive areas of habitat) then the criteria for success would be set at a higher number.

To facilitate comparison with the other two metrics (low scores always indicated lower effectiveness) we used the equation:

$1/\Sigma$ (a, b, c)

Results presented in Table 3.4 indicate that effectiveness based on this metric was high for mink, otter, and gray fox (no crossings over the road surface). However, metric scores for coyote, bobcat, and deer were low, indicating a low level of success relative to a public safety objective (although scores for whitetail deer improved from 2005 to 2006).

2) *Public Safety-Facilitate Some Movement*

Many mitigation projects have combined objectives of reducing animal-vehicle collisions and allowing some degree of movement through the area. If the conservation objective is to maintain population continuity or metapopulation dynamics then it may be acceptable to pass only a portion of population (some inhibitory effect would be acceptable). In this case a useful metric might be:

Σ (e,f,l)/Σ (a,b,c)

This metric places the number of successful movements through the structure in the context of the number of movements at risk for animal-vehicle collisions. The criteria for success would be set at a high number if the level of desired passage (as determined by population modeling) is high and the acceptable risk of collisions is low (ungulates, turtles). The criteria for success might be lower for species whose movement requirements (based on population modeling) are lower and/or the impact of roadkill is less severe.

Scores for this metric (Table 3.4) indicate a high level of success for mink and otter but a score of zero for gray fox. Based on this metric the mitigation was be deemed to be unsuccessful for gray fox because although risk of roadkill was very low, we record no successful crossings for this species. Based on this metric the mitigation measure would be deemed to be relatively unsuccessful for coyote and bobcat and intermediate for fisher (1.0), long-tailed weasel (1.0), raccoon (1.5) and deer (3.0). Scores for deer increased substantially from 2005 (1.33) to 2006 (10.5) to what might be considered a high level of success in this second year.

3) *Reduce Roadkill-Access to Vital Habitats*

Where the objective is to prevent roadkill and provide access to vital habitats for a population, then the metric should seek to evaluate the amount of successful passage in the context of road avoidance or unsuccessful passage (roadkill).

Σ (e,f,l)/Σ (a-d, g-k)

Where access to vital habitats is a concerned, low levels of crossing even when the risk of roadkill is small would be deemed to be unsuccessful. Therefore success would be achieved with a large number of crossings through the structures relative to crossings over the road surface (potential for roadkill) plus unsuccessful crossing efforts (movements parallel or away from the highway).

Based on the scores for this metric (Table 3.4) mitigation success would be high for river otter, mink and deer (for 2006). Poor success is indicated for gray fox, coyote, bobcat and fisher, with intermediate scores for long-tailed weasel, raccoon, and deer (for 2005).

MANAGEMENT IMPLICATIONS

The overall barrier effect created by the road in our study area may be limited for those species we detected through snow-tracking. Conversely, the road may serve as a significant barrier for species that appear to avoiding the area altogether (e.g. – black bear, red fox). Our snow-tracking study provided a useful means for evaluating the overall effectiveness of the Bennington Bypass wildlife crossing structures and has applicability for transportation and wildlife professionals nationwide. A major benefit of snow-tracking is the ability to monitor a large number of continuous sets of animal tracks. Methods such as track beds and remote cameras are useful for determining species use of crossing structures, but provide limited data when evaluating behavioral responses to the structures and use of the surrounding landscape. Snow-tracking is a low cost alternative to telemetry, especially for the smaller study areas associated with crossing structure monitoring. The sample size collected for the effort is quite significant for snow-tracking, relative to the effort required for a similar sample size for a telemetry study.

Although an excellent monitoring technique, snow-tracking provides only winter movement of animals, which may differ from movements during other times of the year. For example, Tierson and colleagues (1985) found that female deer in New York expanded their home ranges in summer and that home range fidelity for both sexes was less pronounced in winter. Parker and Maxwell (1989) studied coyote in New Brunswick and found that their movement patterns changed seasonally from movement through open, mature deciduous-dominated forests in summer to a shift to moving through mature conifer stands in winter. The game trail used heavily in our study area by coyote is dominated by a large stand of eastern white pine (*Pinus strobus*) on the south side of the highway which may explain their heavy use of this area. Litvaitis and colleagues (1987) radio collared bobcat in Maine and found that their movement patterns varied seasonally and was primarily driven by prey availability, predominantly snowshoe hare (*Lepus americanus*).

Our study underlines the importance of developing objectives and the incorporation of landscape scale monitoring when planning mitigation projects. If the goal is to prevent animals' exposure to vehicle collisions, our data suggest these crossing structures are not fully effective. If, alternatively, the primary goal is to enhance permeability of the roadway, allowing a portion of each species' population to cross, then these structures appear to be effective for the species we detected. Greater information on the demographics and population trends of particular species are needed, however, to identify the minimum numbers of crossings per species to maintain population viability and likely effects of road kill on population persistence. In addressing any of these conservation objectives, monitoring should be conducted at a landscape scale, assessing both use and non-use of structures.

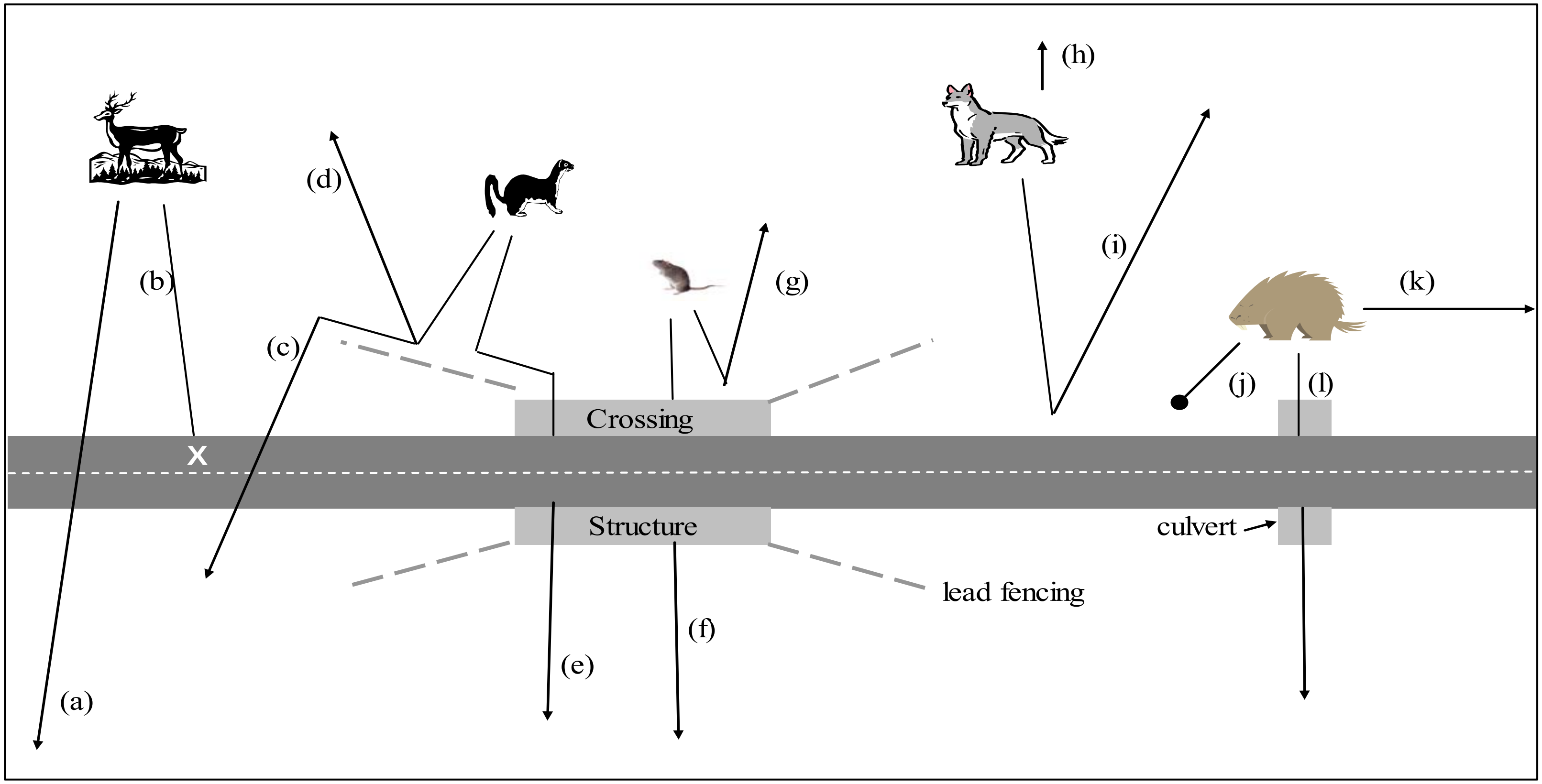

Figure 3.1. Potential wildlife movements relative to roadway and crossing structures (illustrations representative of ALL species) Key: **(a)** move successfully across the roadway, **(b)** vehicle collision, **(c)** approach lead fencing, moving away from passageway around lead fencing , **(d)** approach lead fencing and move away from roadway, **(e)** approach lead fencing and move successfully through passageway, **(f)** move through passageway unabated, **(g)** approach and avoid passageway, **(h)** avoid roadway entirely, **(i)** approach and avoid roadway, **(j)** utilize right of way and **(k)** move parallel to roadway, **(l)** successful crossing through culvert

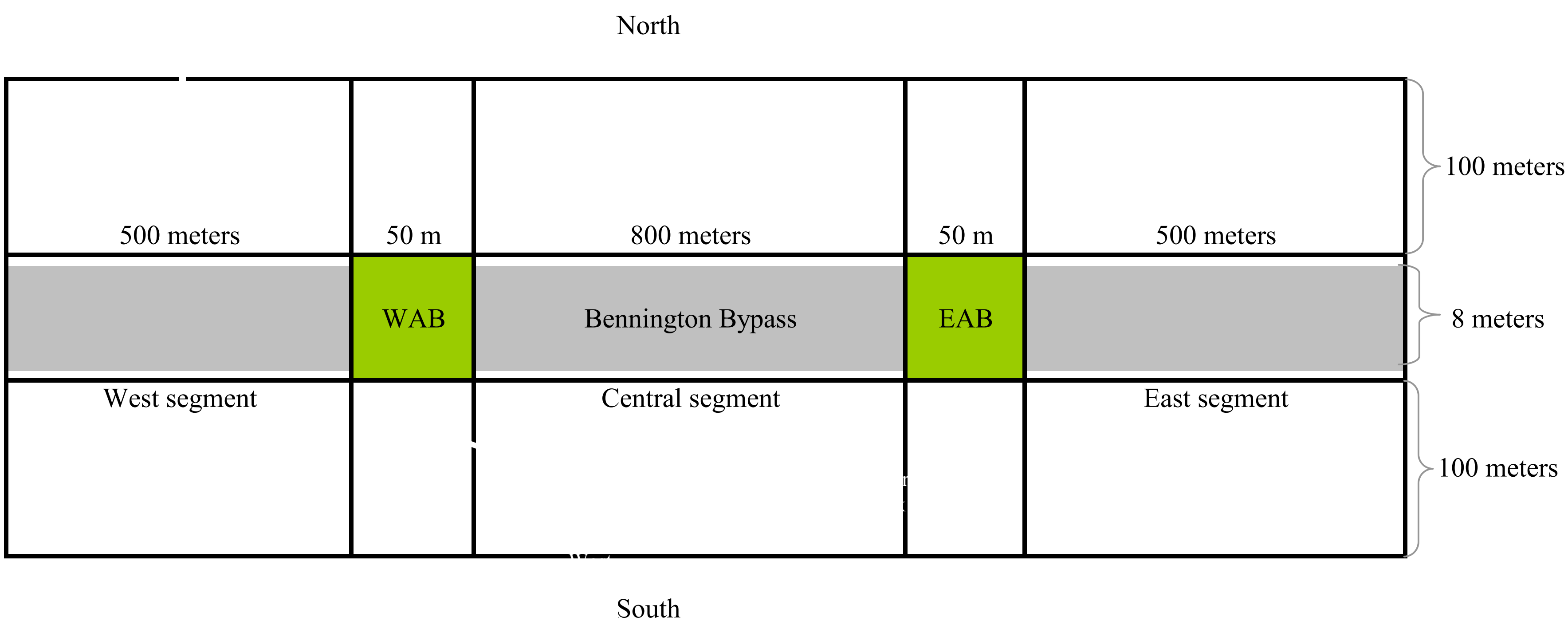

Figure 3.2. Snow-tracking grid at on Highway 279, Bennington, VT

Table 3.1. Number of movements detected for each species. Tracking conducted January 2006 to February 2007 in Bennington, VT. See Fig. 3.1 for definitions of movement types. Deer and domestic cat are listed separately because only crossing data were collected for these species. NI = Pattern Not Identifiable.

	Movement												
Species	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**NI**	**Totals**
Coyote	29	0	2	2	2	6	1	8	4	2	11	18	85
Bobcat	6	0	2	0	0	3	0	4	1	0	1	9	26
Mink	0	0	0	0	1	8	0	0	0	0	1	6	16
Fisher	1	0	1	0	1	1	0	3	0	0	4	3	14
Long-tailed weasel	2	0	0	0	0	2	0	0	0	0	0	4	8
River otter	0	0	0	0	0	3	0	0	0	0	0	3	6
Gray fox	0	0	0	0	0	0	1	0	1	0	0	2	4
Raccoon	1	0	0	0	0	2	0	0	0	0	0	0	3
	39	0	5	2	4	25	2	15	6	2	17	45	162
WT deer	11	-	-	-	-	33	-	-	-	- -	-	-	
Domestic cat	2	-	-	-	-	6	-	-	-	- -	-	-	

Table 3.2. Permeability analysis. Values = movements across roadway/movements along or away from roadway. Higher values suggest higher degrees of permeability. Movements correspond to movements defined in Figure 3.1. Bennington, VT, 2005/06 and 2006/07 winter field seasons.

	Movements														
	Across Roadway						Along or Away from Roadway								
Species	A	C	E	F	L	Totals	B	D	G	H	I	J	K	Totals	Value
Coyote	29	2	2	6	0	39	0	2	1	8	4	2	11	28	1.39
Bobcat	6	2	0	3	0	11	0	0	0	4	1	0	1	6	1.83
Mink	0	0	1	8	0	9	0	0	0	0	0	0	1	1	9
Fisher	1	1	1	1	0	4	0	0	0	3	0	0	4	7	0.57
Long-tailed weasel	2	0	0	2	0	4	0	0	0	0	0	0	0	0	4
River otter	0	0	0	3	0	3	0	0	0	0	0	0	0	0	3
Gray fox	0	0	0	0	0	0	0	0	1	0	1	0	0	2	0
Raccoon	1	0	0	2	0	3	0	0	0	0	0	0	0	0	3
	39	5	4	25	0	73	0	2	2	15	6	2	17	44	1.66

Table 3.3. Analysis of road vs. structure crossings for 2005/06 and 2006/07 field seasons. Movements correspond to movements in Figure 3.1. Lower values represent lower degree of structure use. Highway 279, Bennington, VT, USA.

	Movement					
	Structure crossings[a]			Road crossings[b]		
	E	F	Totals	A	C	Totals
Coyote	2	6	8	29	2	31
Bobcat	0	3	3	6	2	8
Mink	1	8	9	0	0	0
Fisher	1	1	2	1	1	2
Long-tailed weasel	0	2	2	2	0	2
River otter	0	3	3	0	0	0
Raccoon	0	2	2	1	0	1
Domestic cat	0	6	6	2	0	2
White-tailed deer 2005/06	0	12	12	9	0	9
White-tailed deer 2006/07	0	21	21	2	0	2
	4	64	68	52	5	57

[a] - no "L" structure crossing movements detected

Table 3.4. Use of three metrics to evaluate mitigation success by species, Highway 279, Bennington, VT, USA. The “Public Safety Only” metric assumes that preventing wildlife from accessing the road surface is the only objective. The “Public Safety-Facilitate Some Movement” metric represents an effort to both avoid potential wildlife vehicle collisions and facilitate some level of movement from one side of the highway to the other. The “Reduce Roadkill-Access to Vital Habitat” metrics assumes that it is important to both avoid road mortality and facilitate unimpeded access across the highway alignment.

	Metric		
	Public Safety Only	Public Safety - Facilitate Some Movement	Reduce Roadkill - Access to Vital Habitat
	1	e, f, l	e, f. l
	a, b, c	a, b, c	a - d, g - k
Coyote	0.03	0.26	0.14
Bobcat	0.13	0.30	0.21
Mink	High (1/0)	High (9/0)	9
Fisher	0.5	1	0.22
LT weasel	0.5	1	1
River otter	High (1/0)	High (3/0)	High (3/0)
Gray fox	High (1/0)	0	0
Raccoon	1	2	2
WT deer*			
2005	0.11	1.33	--
2006	0.5	10.5	--
Totals	0.09	3	--

*Recorded only movements A and F for this species

CHAPTER 4.

USE OF ROAD KILL SURVEYS TO DETERMINE EFFICACY OF WILDLIFE CROSSING STRUCTURES AND IMPACTS OF TRAFFIC VOLUME ON WILDLIFE MORTALITY

INTRODUCTION

Although roads only cover about 1% of the U. S. landmass, they impact up to twenty times that area (Forman 2000). Impacts on wildlife include direct loss and fragmentation of habitat, modification of behaviors and road mortality (Andrews 1990, Trombulak and Frisselll 2000). The most direct impact of highways is vehicle collisions with wildlife, which can lead to death of animals and safety issues for people. Wildlife/vehicle collisions (WVCs) can result in extensive vehicular damage, often leading to serious injury or fatalities for people. Most WVC data available addresses deer-vehicle collisions (DVC), estimated at between 720,000 and 1.5 million annually (Conover 1997, Forman et al. 2003). Approximately 29,000 injuries and 211 human fatalities occur annually in the United States (Conover et al. 1995).

Road kill is the leading direct human cause of vertebrate mortality. Approximately one million vertebrates are killed daily on roads in the United States (Forman and Alexander 1998). Few, if any terrestrial species are immune to roadkill (Trombulak and Frissell 2000). Due to the higher potential for vehicular damage and human injury/fatalities, the focus of most studies of road kill has been on larger ungulates (Bellis and Graves 1971, Lavsund and Sandegren 1991, Romin and Bissonette 1996*a*).

Recent road kill studies from around the globe cover a wide variety of species ranging from raccoon (*Procyon lotor*; Rolley and Lehman 1992) to green iguanas (*Iguana iguana*; Rodda 1990) to yellow baboons (*Papio cynocephalus linnaeus*; Drews 1995). Because of their need for seasonal movements between different habitats, amphibians may be especially vulnerable to roadkill. Traffic mortality has a significant negative effect on local densities of anurans (Fahrig et al. 1995). The majority of studies on amphibians are conducted in North America and Europe, but more work on this taxa is critical due to the rapid declines of amphibians worldwide (Puky 2006). As research on road kill expands beyond ungulates, so does the variety of approaches taken to mitigate road impacts.

Cramer and Bissonette (2005) reported 460 terrestrial crossing structures in the United States at the time of their review. Wildlife crossing structures have the potential to mitigate the impacts of roads by minimizing road crossings leading to fewer WVCs and reducing animal mortality. The construction of wildlife crossing structures has become more specialized, many now targeting particular species such as: Florida panthers (*Puma concolor coryi*) (Foster and Humphrey 1995), mountain pygmy possum (*Buramys parvus*) (Mansergh and Scotts 1989), and spotted salamanders (*Ambystoma maculatum*) (Jackson and Tyning 1989). Even if the primary goal of species specific crossings is not human safety, it is often considered a valuable byproduct. Conservation goals and safety goals do not have to be mutually exclusive. There is opportunity for collaboration in designing structures that accomplish both safety and conservation goals set forth by transportation and natural resource agencies.

In Vermont, the Agency of Transportation (VTrans) and the Fish & Wildlife Department have been collaborating on wildlife conservation and transportation since 1998 (Austin et al. 2006). As of 2005, Vermont has constructed 9 wildlife crossing structures, two of which are located along the Bennington Bypass (Highway 279) in southern Vermont (Cramer and Bissonette 2005). We evaluated the effectiveness of these structures in reducing mortality of wildlife by using road kill data. We tested whether there is a negative correlation between road kill and proximity to the structures. In addition, we tested whether there is a relationship between traffic volume and road kill.

METHODS

We conducted road kill surveys along the entire 7km of the bypass three times a week (Mondays, Wednesdays, and Fridays), weather permitting. In 2005 we conducted surveys between 21 June and 26 August, in 2006 between 14 April and 16 October and between 24 April and 15 October in 2007. Driving at 15 mph, each side of the road was scanned continuously, noting all animal carcasses. For each road kill we found, we recorded the species, direction traveling, and location to the tenth of a mile (using odometer readings). We classified road kill into size groupings of small, medium or large animals. We considered small animals to be anything that appeared smaller than a rabbit, medium animals to be anything from rabbit size to coyote (*Canis latrans*) size, and large animals to be white-tailed deer (*Odocoileus virginianus*) size or larger. We classified most snakes as medium and turtles as small animals. We did not incorporate birds into our analysis, since the crossing structures were chiefly designed for terrestrial species.

We used a monthly, road kill per survey (RPS) index (number of road kills/number of surveys) as the smallest sampling unit for our analyses (Table 4.1). We conducted our analyses using groupings of species due to the difficulty in differentiating species when animals are dead and flattened by traffic and to account for variation among observers in species identifications.

We evaluated two hypotheses using Pearson Correlations: 1) that road kill decreases with greater proximity to the crossing structures (i.e. increases with distance away from the structures), and 2) that road kill increases with Average Daily Traffic (ADT) levels. We obtained ADT volumes from the VTrans website (Vermont Agency of Transportation 2004) (Table 4.2). For the distance analysis, we analyzed within year correlations using the raw data and across year correlations using indices, since effort (surveys) differed between years. For the traffic volume analysis we used indices for all calculations since number of surveys varied monthly across all years.

RESULTS

We recorded a total of 1,289 road killed animals during 148 surveys, conducted over three field seasons (2005-07). A total of 128 road killed animals were counted over 18 surveys in 2005, 451 over 68 surveys in 2006, and 710 over 62 surveys in 2007. The majority of the road kill we examined was not identifiable to the level of species. Seventy five percent of the road kill was categorized as small animal.

We found no significant within year correlations between distance from structures and number of road kill for any of the size groups (Table 4.1). For large animals (deer) there was a shift in correlation over time between 2005 ($r = 0.000$, $p = 1.000$) and 2007 (r = -0.746, p = .089) as well as a trend towards correlation overall (r = .391, p = 0.108). Results for large animals should be kept in context since sample sizes were small for this group with only six total deer recorded as being killed in our sampling area over 3 years.

We found few significant correlations between road kills and Average Daily Traffic (ADT). We found no correlations in 2005 or 2007 but found positive correlations between medium (r = -0.919, p = 0.003) and large (r = -0.848, p = 0.016) animal road kills and ADT in 2006 (Table 4.2). When correlating data across years we found no correlations for any grouping although there was a trend towards a positive correlation for small animals across years (r = .421, p = 0.092).

DISCUSSION

We examined road kill as a potential indicator of the effectiveness of wildlife crossing structures. We hypothesized that road kill numbers would decrease with proximity to the structures along a stretch of highway. Although we found no correlation between distance and road kill, this does not mean that the structures are ineffective. Two factors, relatively independent of the presence of the crossing structures, are the most likely contributors to the lack of distance correlation: 1) slope of embankment, and 2) placement of stormwater detention ponds.

One of the embankments closest to the structures has only a slight gradient (17°) as compared with much steeper steep slopes (38°) in most areas located farther (>0.5km) from the crossing structures. Steep embankments are found to discourage movements of wildlife towards road surfaces (Goosem et al. 2001). These variations in gradient are probably more influential in determining location of road kill than the presence of the structures.

Construction of stormwater detention ponds along the road may also be serving as sources of animals crossing the road, with the proximity of road and pond functioning as an ecological trap for pond-breeding amphibians (Pulliam 1988, Battin 2004). The majority of road kill detected in the study consisted of small animals (75%). Thirty-one percent of these were identified as anurans, the largest identifiable group in our survey. It is likely that a large portion of the unidentified small animals were also anurans. There are three stormwater detention ponds adjacent to the roadway, two of which we found heavily populated by eastern American toad (*Bufo a. americanus*), northern spring peeper (*Pseudacris c. crucifer*), gray treefrog (*Hyla versicolor*), bullfrog (*Rana catesbeiana*), green frog (*Rana clamitans melanota*), and wood frog (*Rana sylvatica*). The ponds appeared to provide viable breeding habitat for all of these species. However, the proximity of the ponds to the Bypass (15m) also put many of the animals at risk. Adult frogs and toads may be less susceptible to road kill since they typically migrate away from breeding ponds along similar routes from those which they entered, but juvenile dispersal is much less directed, making them more likely to enter the roadway (Semlitsch 2007). This source-trap dynamic likely accounts for the few trends we found toward a relationship between road kill and proximity to crossing structures.

For larger species such as deer, the number of animals hit by vehicles was relatively low (n = 6) over the three years of surveys, especially when considering the high numbers of deer observed in the area during other portions of our study. Larger animals, and deer in particular, receive a great deal of attention in studies of animal-vehicle collisions, due primarily to their large numbers, high visibility and high potential for causing vehicle damage and personal injury. Based on number of deer observed throughout the area and recorded on cameras during other portions of our study, we believe that many are successfully crossing the road, even with the medium traffic volumes along the Bypass. Our findings are consistent with Alexander et al. (2005*b*) who found that permeability for larger fauna, measured by successful road crossings, did not vary significantly with traffic volume. Similarly, Case (1978) found no monthly or annual correlation between ADT and medium and large road killed animals.

One set of data that we excluded from our analyses was information on road killed birds. We found a surprising number of birds (n = 38) during our three years of road kill surveys. Large stretches of the Bennington Bypass are above grade, which puts most of the road surface at tree top level. Thus, the elevated roadway appears to make birds flying from tree to tree across the roadway vulnerable to vehicle collisions, findings supported by Clevenger et al. (2003). Given the small number of road killed birds we did not analyze the distribution of bird carcasses.

The majority of studies that have analyzed road kill across taxa group are relatively outdated and based on single-trip road counts (Forman et al. 2003). A multi-taxa study by Stoner (1936) calculated a mean daily road kill rate of 0.09 animals/km across six studies (ranging geographically from Iowa to Massachusetts), significantly lower than the 0.62 animals/km found in our study. A more recent study by Caro and colleagues (2000) found a mean daily road kill rate of 0.005 animals/km for a variety of species, ranging in size from gray squirrel (*Sciurus carolinensis*) to mule deer (*Odocoileus hemionus*), along a rural highway in California. Smaller animals such as amphibians did not appear in the Caro study, while the Stoner study recorded only 1% of the road kills as amphibians, compared to ≥31% amphibian road kills in our study. The high number of amphibian road kills in our surveys supports findings by Fahrig et al. (1995) and Carr and Fahrig (2001), whose studies reveal that the high rate of anuran road kills are probably contributing to declines in amphibian populations worldwide, particularly in populated areas. Although the results of these studies vary, the findings emphasize the significant impact of our country's highways on wildlife populations, especially smaller taxa such as amphibians.

MANAGEMENT IMPLICATIONS

Without pre-determined objectives, it is difficult to assess the effectiveness of the crossing structures in reducing road kill. The crossing structures at the Bennington Bypass were not designed to support smaller animals or amphibians, which generally require barrier wall and culvert systems for passage across roads (Dodd et al. 2004). However, the high numbers of road killed animals in this category, 75% of all road kill detected in the study, underlines the importance of considering smaller taxa when mitigating for road impacts.

Many larger animals are also clearly being killed on the Bypass, despite the presence of structures designed mainly with these species in mind. However, results of additional monitoring we conducted (Chapters 2 & 3) suggests that most of the larger species detected in the study area may be using the crossing structures and that the road poses little or no barrier to their movement across the study area. The regular use of the crossing structures likely reduces the number of damaging vehicle collisions, a desirable outcome. Clearly, the structures are mitigating some but not all of the impacts of the Bypass on wildlife and people.

Table 4.1. Number of road kills and indices for each species group at varying distances for 2005/06/07 field seasons. Index = number road kills/number surveys. P values calculated using Pearson's correlation. Within year comparisons calculated on raw data (same # surveys), across years on normalized data (indices) to account for between year differences in # surveys. Bennington, VT.

		Distance from crossing structures (miles)												
		0 - .2		.3 - .4		.5 - .6		.7 - .8		.9 - 1.0		1.1 -1.2		
Size	Year	Index	#	Index	#	Index	#	Index	#	Index	#	Index	#	*P*
	2005	0.50	9	1.17	21	0.94	17	1.28	23	0.56	10	0.28	5	0.733
Small animal[a]	2006	0.41	28	0.40	27	0.49	33	0.47	32	0.37	25	0.47	32	0.861
	2007	1.31	81	0.74	46	0.61	38	0.89	55	0.87	54	0.60	37	0.506
	Average	0.74	39.3	0.77	31.3	0.68	29.3	0.88	36.7	0.60	29.7	0.45	24.7	0.267
	2005	0.00	0	0.06	1	0.00	0	0.06	1	0.00	0	0.06	1	0.503
Medium animal[b]	2006	0.25	17	0.21	14	0.29	20	0.25	17	0.18	12	0.13	9	0.688
	2007	0.26	16	0.26	16	0.34	21	0.24	15	0.18	11	0.10	6	0.221
	Average	0.17	11	0.18	10.3	0.21	13.7	0.18	11	0.12	7.7	0.10	5.3	0.304
	2005	0.00	0	0.00	0	0.00	0	0.06	1	0.00	0	0.06	1	1.000
Large animal[c]	2006	0.01	1	0.00	0	0.00	0	0.01	1	0.01	1	0.00	0	0.138
	2007	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.02	1	0.089
	Average	0.00	0.3	0.00	0	0.00	0	0.02	0.7	0.00	0.3	0.03	0.7	0.108

[a] = smaller than a rabbit, [b] = rabbit to coyote size, [c] = white-tailed deer

Table 4.2. Number of monthly road kills and indices for species groups during 2005/06/07 field seasons. Index = number road kills/number surveys. P values calculated using Pearson's correlation on normalized data (indices). ADT = Average Daily Traffic. Monthly Average Daily Traffic (ADT) for Highway 279, Bennington, VT.

		Month														
		April		May		June		July		August		September		October		
Year	Grouping	#	Index	#	Index	#	Index	#	Index	#	Index	#	Index	#	Index	*P*
	Small					2	0.67	59	5.90	60	12.00					0.152
2005	Medium					0	0.00	1	0.10	5	1.00					0.400
	Large					1	0.33	0	0.00	0	0.00					0.209
	Totals					3	1.00	60	6.00	65	13.00					0.280
	ADT					4,290		4437		4509						
	Small	81	11.57	17	1.89	9	1.13	61	5.08	74	6.17	33	3.00	24	3.43	0.392
2006	Medium	53	7.57	37	4.11	20	2.50	21	1.75	8	0.67	3	0.27	5	0.71	**0.003**
	Large	1	0.14	2	0.22	1	0.13	0	0.00	0	0.00	1	0.09	0	0.00	**0.016**
	Totals	135	19.28	56	6.22	30	3.76	82	6.83	82	6.83	37	3.36	29	4.14	0.085
	ADT	4,426		4,691		4,939		5,245		5,319		5,045		5,259		
	Small	19	6.33	74	6.73	85	8.50	140	12.73	190	21.10	33	4.13	10	2.00	0.282
2007	Medium	11	3.67	37	3.36	57	5.70	17	1.55	22	2.44	9	1.13	2	0.40	0.369
	Large	1	0.33	0	0.00	1	0.10	0	0.00	0	0.00	1	0.13	1	0.20	0.458
	Totals	31	10.33	111	10.09	143	14.30	157	14.28	212	23.54	43	5.38	13	2.60	0.469
	ADT	4,747		4,968		5,198		5,385		7,578		7,170		5,516		

CHAPTER 5.

ASSESSING THE USE OF WILDLIFE CROSSING STRUCTURES BY SMALL MAMMALS USING MARK/RECAPTURE MONITORING

INTRODUCTION

Roadways affect wildlife through direct mortality from vehicles, habitat loss and fragmentation and modification of animal movements. These effects can isolate wildlife populations, thereby disrupting gene flow and metapopulation dynamics (Andrews 1990; Bennett 1991; De Santo and Smith 1993; Jackson 1999; Trombulak and Frissell 2000). Small mammals are particularly affected by these isolating mechanisms due to their low dispersal capabilities and low probability of surviving highway-crossing attempts (Conrey and Mills 2001), and roads may serve as a biological sink where low-quality habitat and greater predator access leads to depleted populations (Forman et al. 2003).

Small mammals play pivotal roles in ecosystem processes as prey for reptilian, avian and mammalian predators, consumers of invertebrates and plants, and dispersers of many plant species (Carey and Johnson 1995). Roads inhibit the movement of small mammals (Oxley et al. 1974), which may lead to local extinctions, social disturbance and morphological divergence (Dickman and Doncaster 1987). Numerous studies document the effects of roads on small mammals (Adams and Geis 1983, Clark et al. 2001, Kozel and Flaherty 1979, Oxley et al. 1974, McDonald and St. Clair 2004*a*, Forman et al. 2003, Conrey and Mills 2001, Garland and Bradley 1984), but few studies report on the effectiveness of crossing structures to mitigate these impacts. McDonald and St. Clair (2004*a,b*) tested the efficacy of crossing structures for murid rodents in Banff National Park. In Montana, installation of protective tubes increased meadow vole (*Microtus pennsylvanicus*) movements under a highway through a culvert (Foresman 2004*a*, Foresman 2004*b*). Similarly, Linden (1997) reported that the construction of stump rows facilitated small mammal movements through a viaduct under a highway in Zandheuvel, Netherlands.

We used a mark/recapture study to determine 1) is the road a barrier or impediment to small mammal movement (either via mortality or behavioral avoidance), and 2) do the crossing structures facilitate movement across the road. We addressed these questions by fitting landscape resistances to the road and passages (as well as streams flowing through the plots). This approach allows us to represent landscapes as presenting varying levels of resistance to animal migration and dispersal, as opposed to a simplistically representing features as either barriers or corridors (Ricketts 2001). We estimated a resistance value for each land cover type with a novel approach that maximizes the difference between least-cost paths of empirical movements of mice with the least-cost paths of randomly generated null mouse paths across the parameter space (Compton and McGarigal in prep.). This allowed us to estimate the resistance of the road and passage structures to mouse movements relative to forest.

METHODS

We captured small mammals adjacent to the two crossing structures using Sherman live traps (n = 226) following guidelines outlined by ASM (Gannon et al. 2007) and approved by the University of Massachusetts at Amherst Institutional Animal Care and Use Committee. Fourteen 500m-long transects were established parallel to the roadway with four transects on each side of the West Airport Brook (WAB) crossing structure and three transects on each side of the East Airport Brook (EAB) structure (Fig. 5.1). A wetland and limited access to private property reduced the number of transects used at EAB. Transects were spaced 50m apart into the adjacent forest. During part of the first field season in 2006 (31 May – 14 Aug), the first transect was placed in the adjacent forest 50m from the roadway. For the last part of the 2006 field season and the entire 2007 field season, this first transect was moved closer to the roadway to align with the forest edge (~ 35m from the roadway). Traps were set at 25m intervals along each transect, except for the 50m-wide area directly adjacent to the crossing structure where we placed traps 10m apart during trapping periods.

With four sets of trap transects (one on each side of the two crossing structures), we attempted to trap for two to three nights in each set of transects monthly depending on weather conditions. We chose this long interval between trap sessions within a set of transects to reduce the potential for "trap-happy" or "trap-shy" animals (Sheppe 1967; Renzulli et al. 1980; Menkens and Anderson 1988). We baited traps with peanut butter and supplied cotton for nesting material, and placed them at habitat features (i.e. logs, trees, burrows) within 1m of each trapping point in the late afternoon. Captured animals are identified, sexed, aged, marked with metal ear tag (if unmarked), tag number and station number were recorded, and the animal released at the capture location. We were unable to reliably distinguish between deer mice (*Peromyscus maniculatus*) and white-footed mice (*Peromyscus leucopus*) in the field, thus we recorded these two species as *Peromyscus* spp. Similarly, we were unable to identify the species of jumping mice captured, thus these species were recorded as *Zapodidae*. Traps which contained animals were re-baited and reset for the duration of the trapping session. All traps were collected at the end of each trapping session to reduce habituation to traps. We calculated distance traveled by calculating distances between recaptures.

Data Analysis

Our estimates of landscape resistance were based almost exclusively on movements of *Peromyscus* (referred to as mice from here forward) among traps. Thus, we dropped all mice that were caught only in a single trap (one or more times). We also dropped two mice that crossed between the two trapping grids (≥ .3km), and three mice caught in traps on June of 2006 at a landowner's request. Although the placement of traps near the passage entrances was not consistent across the two seasons [described above], we treated all traps as existing throughout the study, because the inconsistent traps were very close to each other. Estimates were based on 991 captures of 305 mice. Only 13 of these mice were trapped on both sides of the road.

We used a novel method to estimate landscape resistance from the trapping data, described in more detail in Compton and McGarigal (in prep.). We randomly generated null "pseudomice" (Fig. 5.2) with trap capture patterns that matched empirical mouse patterns (number of traps, distance among traps, and total movement length). Pseudomice move like real mice, but they have no knowledge of the landscape because movements were generated without regard to landcover data. If the null model (all resistances = 1) were true, empirical and pseudomice would be indistinguishable. In the real world, however, mice are optimizing their movements in regard to the landscape. Thus, given the “true” set of landscape resistance parameters, the movements of real mice should approximate least cost paths, while pseudomice, having no knowledge of the landscape, move without regard to path costs. The difference between least-cost paths should be maximized for the set of parameters that best represent the resistances mice encounter in the landscape.

We mapped the traps, road, passages, and the permanent and intermittent stream in a 2 m grid. All areas that were not mapped as road, passages, or streams were considered forest. We then ran 10,000 simulations. For each simulation, we randomly selected a set of resistance parameters between 1 and 1000 (for road, passage, intermittent stream, and permanent stream; the resistance of forest was always set at 1.0). We used a logarithmic scale in order to get better estimates of lower resistance values. We then measured the total least-cost path of each of 305 mice, and the least-cost path of 305 randomly generated pseudomice (new pseudomice were generated for each simulation). We then calculated a normalized difference (Δi) for each simulation i based on the sum of squared least-cost paths:

$$\Delta_i = \frac{\sum_{j=1}^{305} LCP\left(pseudomouse_j\right)^2 - \sum_{j=1}^{305} LCP\left(mouse_j\right)^2}{\sum_{j=1}^{305} LCP\left(mouse_j\right)^2}$$

where LCP (mousej) is the least-cost path through the sequence of traps where mousej was caught. We squared LCPs to emphasize the higher-cost paths taken by mice and pseudomice, because most movements are uninformative low-cost movements through forest.

The result was a dataset of 10,000 resistance values for each parameter and a corresponding Δi. We then used multiple quadratic regression to fit Δi to the parameters. The parameter value that maximized Δi (Zar 1996, pp. 453-454) was our estimated resistance value. Significance for each parameter was based on the t-statistic of the squared term; positive (U-shaped curve) or insignificant (> 0.05) parameters were considered inestimable. We used 10,000 bootstrap estimates to calculate 95% confidence intervals on each parameter.

Landscape resistances are interpreted as a multiplier on the cost of moving through habitat; for instance, if forest is given a resistance of 1.0 (the lowest resistance, representing the animal's habitat), and fields are given a resistance of 3.0, the cost of moving 100 m through fields would be the same as the cost of moving 300 m through forest. Resistances represent in integration of willingness to move and mortality, thus, the model combines behavioral avoidance of roads with road mortality, with no means of distinguishing between the two.

Finally, we used the estimated resistances to map the probability of a mouse moving through any part of our study landscape using the resistant kernel approach (Compton et al. 2007). Data analysis and simulations were carried out with programs written by B.W.C. in APL+Win v. 6.0 (APLNow, Brielle, New Jersey) and R v. 2.4.0 (R Foundation for Statistical Computing, Vienna, Austria) and by E. Ene in Visual C++ version 6.0 (Microsoft, Redmond, Washington). The GIS representation of the landscape was prepared in ArcInfo (version 9.2 , Environmental Systems Research Institute, Redlands, California).

RESULTS

We trapped and tagged 690 small mammals over 48 trapping sessions during the 2006 (n = 28 sessions, 31 May – 17 Oct) and 2007 (n = 20 sessions, 8 Jun – 17 Oct) field seasons (Table 5.1). *Peromyscus* spp. were captured most frequently (92%) followed by southern red-backed voles (*Clethrionomys gapperi*)(6%), eastern chipmunks (*Tamias striatus*) (1%) jumping mice (family *Zapodidae*)(< 1%) and meadow vole (*Microtus pennsylvanicus*)(< 1%) . Several other small mammal species were captured including, northern short-tailed shrews (*Blarina brevicauda*)(n = 127), red squirrels (*Tamiasciurus hudsonicus*)(n = 6), long-tailed weasels (*Mustela frenata*)(n = 5) and ermine (*Mustela erminea*)(n = 4). Of the 690 animals tagged, 55% (n = 378) were recaptured at least once.

The recapture rate was slightly higher in 2006 (57%) than in 2007 (52%). On average, recaptured animals were trapped 2.74 times, totaling 1,043 recaptures with average recapture numbers slightly higher in 2007 (3.02) than in 2006 (2.62).

We detected 26 structure crossings by 13 individual *Peromyscus spp.* for the two field seasons, 18 at WAB and 8 at EAB (Table 5.1), and one road crossing by a *Peromyscus spp.* No other species were recorded crossing the road or through the structures.

Based upon the longest distance traveled for each individual recaptured, over 36% of *Peromyscus spp.* (n = 138) moved distances ≥ 65m, the minimum distance needed to move between the two adjacent forest edges through one of the crossing structures. The 13 animals detected moving through the crossing structures represent 4.7% of recaptured animals. There was strong positive correlation between distance traveled and time between recaptures for all small mammals in 2006 ($r = 0.239$, $n = 232$, $p = < 0.001$) and 2007 ($r = 0.326$, $n = 149$, $p = < 0.001$) (Table 5.2).

Data analysis

Multiple regression analysis was able to estimate three of the four parameters: road, passage, and permanent stream (Table 5.3). The estimate for intermittent stream was not different from 1.0, the value assigned to forest. This is unsurprising, because for much of the season, the intermittent stream was dry, and on the whole it may have presented very little impediment to mouse movement. The estimate for the road (224.7) was far higher than the value assigned to forest (1.0), indicating that the road is a strong impediment to mouse movement and perhaps a complete barrier. The resistance of the passages (9.6) is far less than the resistance of the road, suggesting that although mice were more reluctant to use the passages than the forest, they did provide a viable corridor through the otherwise nearly impassible road.

Confidence intervals for the road were broader than those for the passage or permanent stream, perhaps because we generated random parameters on a logarithm scale with the goal of better estimating small resistances. We mapped the probability of mice moving through any part of our study landscape (Table 5.3)

DISCUSSION

Numerous studies suggest that roads inhibit small mammal movements (Oxley et al. 1974; Garland and Bradley 1984; Conrey and Mills 2001; MacDonald and St. Clair 2004a) but few have evaluated the degree of impediment relative to the natural landscape. Our study accomplished this by comparing movements in a forested landscape to those across a roadway, providing strong empirical data that roads serve as extreme barriers to movement for small mammals. When evaluating resistance levels results from our study suggest the road imposes a significantly higher resistance to movement (224.7) than the forest (1.0), a perennial stream (5.0), and the crossing structures (9.6) (Table 5.3).

Several factors may be restricting small mammal movements across the road surface, including the grassy vegetative communities in the 50m-wide right-of-way (ROW) on both sides of the roadway and the wide expanse of asphalt. Adams and Geiss (1983) reported higher densities of small mammals in grassy ROWs, but increased instances of road-killed animals along roadways. In our study area, the grassy ROW probably provided more favorable habitat for meadow voles but would be an atypical habitat for white-footed mice (Grant 1971; Kaufman and Flaherty 1974). Our findings are consistent with previously reported results that focused on small mammal movements across road surfaces. Kozel and Fleharty (1979) reported that white-footed mice were reluctant to venture onto road surfaces when distances between forest edges exceeded 20m. Clark et al. (2001) used a mark-recapture technique similar to ours and determined that *Peromyscus spp.* were reluctant to cross a narrow (6m), two-lane asphalt road when compared to a similar width dirt road. Small mammal reluctance to cross the roadway may be more related to the lack of cover on the roadway rather than the surface itself since movement across the road exposes these prey species to mammalian carnivores and raptors (Foresman 2004*b*).

Although there is a paucity of information on the effects of natural barriers on small mammals, results from our study support findings from the few studies that investigated the effects of streams on their movements. Savidge (1973) relocated northern white-footed mice (*Peromyscus leucopus noveboracensis*) across a stream in Pennsylvania similar in depth and width to the perennial stream in our study area, and found that the homing probability of animals moving across the stream was much lower than homing to an area without a stream ($P>0.05$). Much of the barrier effect created by the stream can be attributed to the poor swimming ability of white-footed mice (Carter and Merritt 1981). This may explain the almost total absence of stream crossings in the Savidge study, where logs or obstructions were absent, providing no opportunity for dry passage. The lack of an extreme barrier effect in our study may be explained by the presence of several downed trees that traversed the stream, providing potential passage for small mammals. Resistance of the intermittent stream was not found to be significantly different from that of forest.

Our analysis suggests the crossing structures mitigate much of the barrier effect created by the road but still serves as an impediment to movement (Table 5.3). Possible explanations include the extremely large openness ratios (structure width x height/length) of the two crossing structures we studied. McDonald and St. Clair (2004*b*) found that small mammals, including three of the species found in our study area (deer mouse, meadow and red-backed voles), had much higher success moving through smaller than larger crossing structures which they attributed to greater overhead cover in the smaller structures. There is evidence that large structures have the potential to serve as ecological sinks for small mammals since predators may occupy the areas within the structures, greatly inhibiting use of those structures by prey species (Hunt et al. 1987; Clevenger and Waltho 1999). Further, the entrances to the two crossing structures in our study had limited natural vegetation, another factor limiting crossing structure use (McDonald and St. Clair 2004*b*; Rodriguez et al. 1996; Rosell et al. 1997; Santolini et al. 1997; Clevenger and Waltho 1999). Based on these findings we recommend that restoring the natural vegetative community within structures become a major consideration during the planning stage of construction.

MANAGEMENT IMPLICATIONS

Highways are landscape features with exceptionally high resistance values for mice (*Peromyscus spp.*). In the absence of alternative methods for crossing highways it is unlikely that mice will cross in sufficient numbers to maintain population cohesion or meta-population processes. Cover (vegetation, woody debris, rocks & crevices) is an important consideration in crossing design for small mammals, especially for large structures. The willingness of small mammals to use very small structures means that they may be able to use drainage culverts, stream crossings, and road underpasses as ways to cross highway alignments without passing over the road surface.

Conclusions from our study underline the importance of setting pre-construction objectives for wildlife crossing structures. Although in general bigger is better this applies to larger mammals. If crossing structures are designed for use by a single species they may act as barriers for other species with different requirements (Jackson and Griffin 2000). A broader approach to mitigation design should consider ecosystem processes including prey species such as *Peromyscus spp*. Even if crossing structures are not designed specifically for small mammals modification of existing structures may prove just as effective. For example, in Montana, installation of protective tubes increased meadow vole (*Microtus pennsylvanicus*) movements under a highway through a culvert (Foresman 2004*b*). Similarly, Linden (1997) reported that the construction of stump rows facilitated small mammal movements through a viaduct under a highway in Zandheuvel, Netherlands.

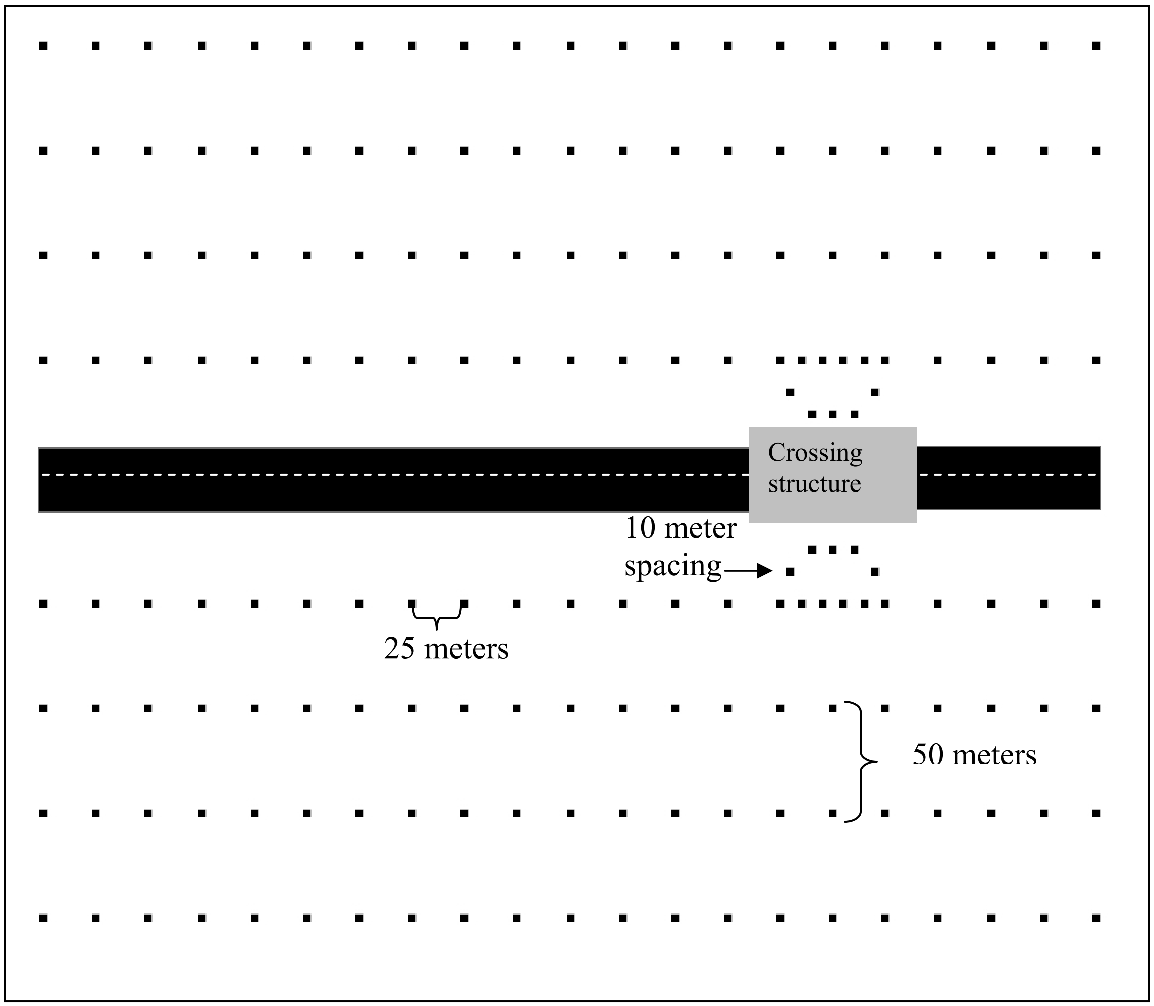

Figure 5.1. Small mammal trapping grid. Bennington, VT. Small squares = trap locations.

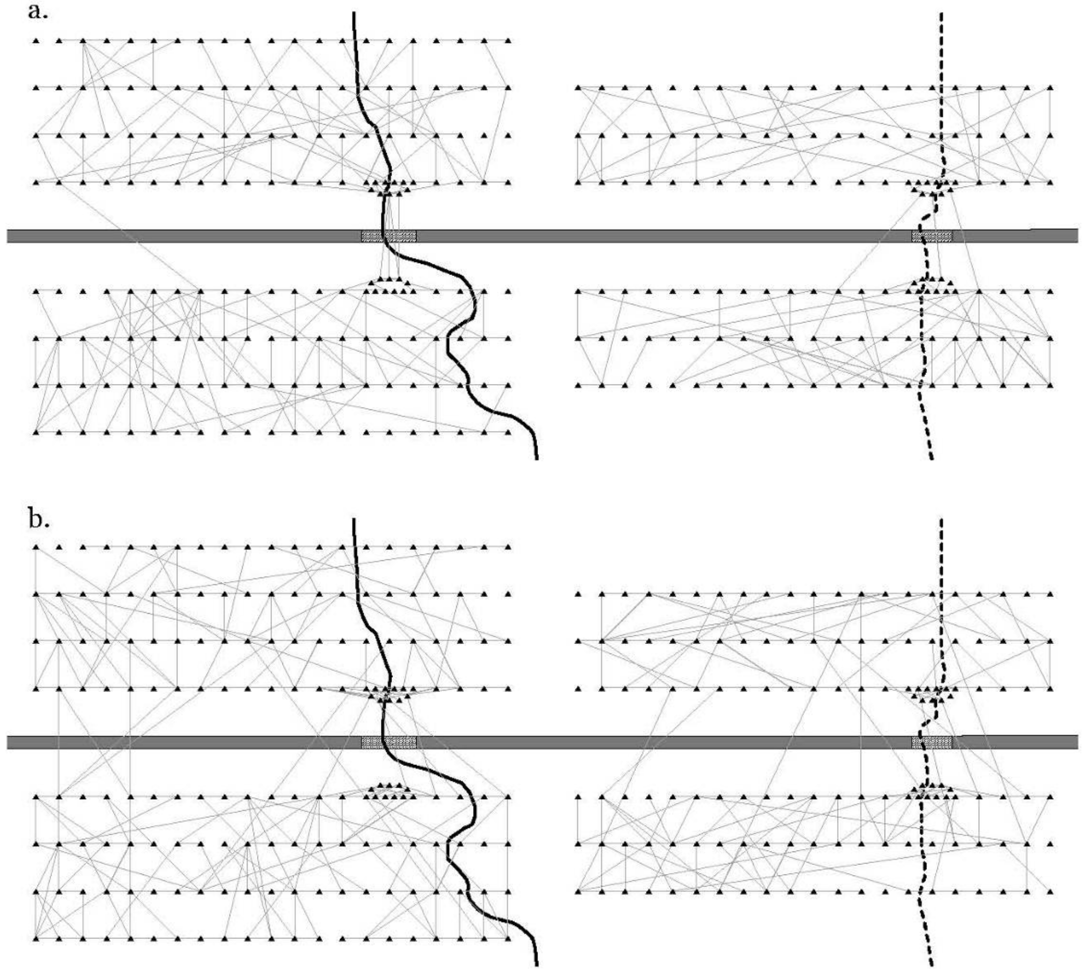

Figure 5.2 Landscape with (a) mouse movements, and (b) sample pseudomouse movements. Road is depicted as dark gray, passages are hatched, streams are solid line (perennial) and dotted line (intermittent), traps are triangles. Inferred mouse and pseudomouse movements between traps are shown as light gray lines. Although east and west trapping grids are show side-by-side, actual grids are .3km apart. Grids were treated as disjunct in the model.

Table 5.1. Numbers of four species of small mammals captured, marked, recaptured, and roadway crossings adjacent to the West Airport Brook (WAB) and East Airport Brook (EAB) crossing structures along Highway 279, Bennington, VT in 2006 and 2007.

	2006		2007		
	WAB	EAB	WAB	EAB	Totals
Species	# individuals tagged				
Peromyscus	251	154	108	122	635
Red back vole	12	15	1	12	40
Eastern chipmunk	4	0	1	2	7
Zapodidae	2	0	0	0	2
Meadow vole	3	2	1	0	6
	272	171	111	136	690
	# individuals recaptured				
Peromyscus	143	92	59	65	359
Red back vole	7	4	0	4	15
Eastern chipmunk	2	0	0	0	2
Zapodidae	2	0	0	0	2
	154	96	59	69	378
% recaptured	57%	57%	53%	51%	55%
	Total number of recaptures				
Peromyscus	452	183	213	163	1011
Red back vole	7	5	0	4	16
Eastern chipmunk	3	0	0	0	3
Zapodidae	6	0	0	0	6
	468	188	213	174	1043
recapture rate[a]	3.12	1.98	3.61	2.52	2.74
	# passage crossings				
Peromyscus	11	4	7	4	26
(# individuals)	(4)	(2)	(5)	(2)	(13)
	# road crossings				
Peromyscus	0	0	0	1	1

[a] = calculated for recaptured animals only.

Table 5.2. Average distances moved by time period from mark/recapture study of 684 small mammals adjacent to two crossing structures along Highway 279, Bennington, VT in 2006 and 2007.

	2006		2007	
Time Period	N	distance (m)	N	distance (m)
< 1 week	75	43.1	35	43.3
1 - 2 weeks	34	60.1	14	86.6
2 - 4 weeks	78	76.2	36	63.5

Table 5.3 Estimated resistance values for each land cover type, 95% bootstrapped confidence intervals, and P-values from multiple regression. Forest is given a resistance of 1.0 (the smallest) by definition; other resistances are relative to forest. Note that intermittent stream is the only cover type with a resistance that is not significantly different from forest.

Land cover type	**Resistance**	**95% CI**	***P***
Forest	1.0		
Road	224.7	(154.3 - 387.5)	< 0.001
Passage	9.6	(7.9 - 11.3)	< 0.001
Intermittent stream	29.2	(0.9 - 351.4)	0.107
Permanent stream	5.0	(4.4 - 5.6)	< 0.001

CHAPTER 6.

SYNTHESIS AND RECOMMENDATIONS

SYNTHESIS

The wildlife crossing structures constructed on the Bennington Bypass represent two very different mitigation options: large expanded bridges with a very high degree of openness (86-97.4m) and abundant vegetation and a long culvert with a very low degree of openness (0.02m) and completely lacking in substrate or vegetation. The expanded bridges account for the vast majority of mitigation achieved at this site.

Although we documented five species using the culvert only one species (ermine) used this structure substantially more than the expanded bridges. Ermines were documented 25 times crossing through the culvert as opposed to only once at the expanded bridges. This is consistent with other research that indicates that ermines prefer smaller, more confined structures (Clevenger et al. 2001*a*). However, it is also possible that the majority of these 25 crossings represent the movements of one or two animals whose territory happened to coincide with the culvert location. It is also possible that ermine use of the expanded bridges will increase as vegetation and other elements of cover (woody debris) continue to develop within the crossing structures.

There are a number of reasons why the culvert was not more effective in providing passage for wildlife. The culvert is probably too small to pass moose and perhaps black bear and deer. The small openness ratio (0.02m) is also likely to be an important factor for larger wildlife (moose, bear, and deer). Studies suggest that deer prefer to use structures with openness ratios greater than 0.46m (Brudin 2003, Reed et al. 1979, Reed 1981). The very low degree of openness for this structure may also affect mid-sized mammals such as coyotes, bobcat, foxes and fisher. Other factors that may be negatively affecting wildlife use of the structure are the large angular rip rap at the entrances (Fig. 6.1) and the lack of any substrate within the corrugated metal pipe (Fig. 6.2).

The expanded bridges were used by a wide range of animal species. The large size, openness, and vegetative cover are features that undoubtedly contribute to their effectiveness for most species. The presence of streams running through the structures likely contributed to their use by mink and otter.

Despite the general high level of wildlife use of the two expanded bridges there are two reasons for concern about the overall effectiveness of the mitigation as it pertains to some species. We documented no crossings for moose, black bear, red fox and gray fox. It is unclear whether these species are avoiding areas near the highway or simply were not present in the area where our monitoring was conducted. A second concern is that deer, bobcats and coyotes continue to cross the highway over the road surface, providing ongoing opportunities for wildlife-vehicle collisions. This later issue likely has more to do with the ineffectiveness of the right-of-way fencing than any shortcoming of the structures themselves (Fig. 6.3).

Wildlife Response

In reviewing the various components of the Bennington Bypass study, it is apparent that wildlife responses to the road and the crossing structures vary among species. The following is an assessment of species/taxa specific responses to the roadway and crossing structures.

Small mammals (primarily white footed and deer mice)

The roadway appears to serve as a significant barrier to movement to small mammals. Only one of the 378 recaptured animals crossed the highway (Table 5.1). Although this barrier effects was mitigated to some degree by the crossing structures, small mammals moved through the crossing structures in lower proportions than expected based on data collected on their movements in the surrounding habitat. Two primary factors most likely contribute to the barrier effect created by the road, 1) unsuitable small mammal habitat in areas adjacent to the roadway and within the crossing structures, and 2) lack of cover within the structures. The grassy right-of-way sharply contrasts from the natural wooded habitat in the adjacent forest. This grassy habitat may support meadow vole populations but may also make them more vulnerable to road kill (Grant 1971). In contrast, this habitat restricts movements by deer and white footed mice

(King 1968). Research by Foresman (2004*b*) suggests that the inclusion of cover in crossing structures greatly enhances permeability for small mammals. It is possible that as vegetation and other habitat structure (woody debris) continues to develop within the structures small mammal passage will increase.

Ermine/Long-tailed weasel

The limited use of the large crossing structures for both of these species (Tables 2.1 and 3.1) and the relatively high use of the culvert by ermine is consistent with findings by Clevenger et al. (2001*a*). These small weasels prefer wooded areas where prey species such as white footed and deer mice are prevalent. Similarly to small mammals, they tend to use structures with low openness ratios, such as the culvert, in order to avoid exposure to predators. The culvert provided opportunities for ermine passage that were not being provided by the expanded bridges. However, it is possible that the majority of the 25 ermine crossings documented through the culvert represent the home range movements of one or two individuals.

Long-tailed weasels were only once documented using the culvert and used the expanded bridges for six crossings over the course of three field seasons. Snow tracking documented few long-tailed weasel trails over two winter seasons (Table 3.1) with data indicating that this species crossed over the road surface in numbers (2) equal to crossings through structures (2).

Use of the expanded bridges by both weasel species may increase over time as vegetation and other elements of cover (woody debris) continue to develop within the expanded bridges.

Mink/River Otter

The crossing structures are quite effective for semi-aquatic species such as mink and otter due to their placement along stream corridors. Both species scored high on all three metrics used to evaluate mitigation success (Table 3.4). The streams served as travel corridors and also provided suitable foraging habitat for both species (Melquist and Hornocker 1983). It is possible that both species would have used the structures even if they were significantly smaller, given that neither species was detected using areas outside the stream bank. Mink were also documented using the culvert (six crossings). However, it is not known what role openness plays in facilitating structure use by river otters.

Fisher

The low number of detections on the track beds and absence of camera detections in conjunction with the limited number of crossings recorded during winter would suggest that the structures are not highly suitable for fisher (Tables 2.1 and 3.1). Fishers were documented using the expanded bridge crossing structures only six times over three field seasons (three summers and two winters) and were never documented using the culvert. Snow tracking data indicate that fishers crossed over the road surface (2) as often as they used the crossing structures (2). As a result fishers received an intermediate score for the second metric (Public Safety-Facilitate Some Movement, Table 3.4). Documentation of seven sets of tracks moving either away from or parallel to the highway indicate possible road avoidance resulting in a low score for metric #3 (Reduce Roadkill-Access to Vital Habitat, Table 3.4). The risk for road mortality and the evidence for road avoidance suggest that the crossing structures are not fully mitigating the negative impacts of the highway for this species.

The lack of forested habitat at the approaches to and within the expanded bridges may be inhibiting fisher from using these structures given that they prefer foraging in forested habitat and avoid open areas in winter (Powell 1994). The riparian areas within the structures would generally be favorable habitat for fisher but the lack of canopy cover in these areas may inhibit their movement (Witmer et al. 1998). It is possible that fisher use of the crossing structures could increase over time, either because of learning/acclimation or as a result of continued development of woody vegetation and debris within the structures.

Bobcat

Bobcats appear to be prevalent in the area but they do not show a strong preference for using either the road or crossing structures. They were detected using the road more frequently (8) than the structures (3) for crossing during our snow-tracking study (Table 3.1) but their propensity in summer is unknown. Although we recorded numerous bobcat crossings both at the track beds (7) and with the cameras (9) during the summer, the proportion of road vs. structure crossings during this period is unknown since we were unable to detect road crossings during these periods (Tables 2.1 and 2.3). Many of their road crossings in winter can be attributed to two well used game trails in close proximity to the structures. Bobcats in our study also cross the road in areas where the distances between forest edges at the road were shortest, which supports findings by Cain and colleagues (2003).

Because of the bobcats' propensity to cross over the road surface more often than through the crossing structures, this species received low scores for all three metrics (Table 3.4). Although bobcats are using the expanded bridges (but not the culvert) to move from one side of the highway to the other, there is a significant risk of road mortality. As a result the crossing structures are currently only partially mitigating the highway's effects on this species. However, there are some actions that can be taken (see Recommendations Section) that might reduce road crossings and increase the overall effectiveness of the structures.

Coyote

The high proportion or road (31) vs. structure (8) crossings in winter (Table 3.1) combined with a limited number of structure crossings detected in summer (8) (Table 2.1) would suggest that coyote prefer the road surface for movement across the highway. As a result, coyote scored poorly in all three mitigation metrics (Table 3.4) indicating that the crossing structures are not doing much to mitigate the potential impacts of the highway for this species.

In part, their apparent preference for use of the road for crossing may be attributed to a well used game trail 500m to the west of the WAB and their propensity to forage in the right-of-way. Coyote use of roads is not uncommon and is supported by several studies (Tigas et al. 2002, Arjo and Pletescher 2004). Similar to bobcat, action could be taken that might improve the performance of crossing structures for coyotes (see Recommendations).

White-tailed deer

Based on observations and empirical evidence from cameras, snow-tracking and track beds, white-tailed deer are the most abundant large mammal in the area. Although we did not track deer in areas away from the road during our snow-tracking study, observations of tracks reveal they are abundant and appear to move randomly through the landscape, with no predominant paths used for movement. The randomness of the tracks did not translate to random road crossings. We detected a large shift towards use of the structures over the two winter field seasons (Table 3.3). With this shift in structure use we saw a substantial improvement in the scores for metric 1 (from 0.11 to 0.50) and 2 (from 1.33 to 10.5) (Table 3.4). It is unclear how much of the change in structure use is the result of deer becoming accustomed to the structures or the selective loss (via roadkill) of individual deer with a propensity to cross over the road surface. Based on these results the expanded bridges appear to be mitigating the impacts of the highway on deer, although the risk of deer-vehicle collisions persists.

The low number of road killed deer (7) detected during our three summer field seasons combined with the low number of road crossings detected during our two winter field seasons (11) suggests that deer may be avoiding the road for crossing even though they move in areas adjacent to it. The large openness ratio of both structures appears to be conducive to deer movement while each structure affords different features for crossing. The WAB crossing provides low vegetated, easily traversed habitat while EAB provides some cover along the stream for movement. Even with relatively few road crossings and an apparent shift in use towards the structures, deer still remain at risk and serve as a safety hazard in the area. The risk of collision may increase if the new sections of the Bypass increase traffic in the area.

Woodchuck

Our camera data revealed that woodchucks are inhabiting the areas under the crossing structures and not necessarily moving through them. The rip-rap, providing burrows, and vegetation within WAB appear to provide suitable habitat for woodchuck. Numerous woodchuck road kills were detected during the three summer field seasons suggesting they also use the road edges for foraging and burrowing, findings supported by Oxley and colleagues (1974).

Raccoon/Virginia opossum/Striped skunk

Occasional crossings were detected for these three species (Table 2.1) with no strong patterns of movement. Opossum and skunk were detected using the wider, dry areas at the structures while raccoon showed a propensity to cross along the streams. Raccoons used both expanded bridges as well as the culvert to cross the highway. All of these species were detected during our road kill surveys, suggesting they are also using the road for crossing. The 4-foot right-of-way does not appear to be an impediment for these species.

Wild Turkey

Similar to deer, wild turkeys are abundant in the area and appear to show a preference for using the crossing structures (Table 2.1). A high number of turkeys were detected using the structures and our low number of road kills detected (2) suggests turkeys may be avoiding the road surface, findings supported by Butler and colleagues (2005).

Red/Gray Fox

The habitat in the area adjacent to the Bypass is suitable for both species, with red fox found in a variety of habitats ranging from dense forests to pastures and gray fox inhabiting dense northern hardwood or mixed forests (DeGraaf and Yamasaki 2001). It was unexpected that few signs of gray fox and no red fox were detected in the area given that the habitat is suitable and they are both generally urban adaptive animals (Doncaster and Macdonald 1991, Harrison 1997). Two sets of snow tracks for gray fox documented avoidance of the road (1) and an expanded bridge crossing structure (1). Possible explanations for our observations include: a) active avoidance of areas near the highway, b) low population levels in the area, or c) active avoidance of areas inhabited by coyotes.

Both species are known to coexist in areas populated with coyote (Voigt and Earle 1983, Chamberlain and Leopold 2005) but gray fox have been found to avoid areas with high coyote densities (Farias et al. 2005). Coyote densities are relatively high in the area. Although few coyote detections were made in summer, our snow-tracking detected a high number of coyote tracks throughout the study area. In addition, anecdotal evidence in the form of coyote pack howling was detected on numerous occasions throughout the summer field seasons.

Black Bear

Anecdotal information provided by area game warden Travis Buttle and local landowners, in addition to bear clawed trees suggests that black bear were present in the area prior to construction of the Bypass. These observations may support findings by Brody and Pelton (1989) who found that bear attraction or avoidance of roads depends on the amount of threat perceived by them. In public parks where vehicles drive slowly and humans are seen as a food source, bears are attracted to roads, while in areas with heavy traffic roads may be perceived as a threat. It is unknown whether black bear will repopulate the Bypass area. Clevenger and Waltho (2004) observed a slight increase in crossing structure use by black bears over a period of five years in Banff.

Moose

Local landowners noted that moose were present in the area prior to construction, albeit not numerous. The wetland complex located just south of the Bypass within our study area provides suitable summer foraging habitat for moose but the lack of conifers in the area may not provide suitable winter foraging habitat. In addition, the fragmentation impact of the Bypass may be reducing moose capacity to inhabit the area, findings supported by Schneider and Wasel (2000) who found a linear decline in moose densities corresponding to increases in road densities.

Effectiveness of Monitoring Techniques

Understanding movement patterns relative to the roadway and passage structures are important elements in gaining a better understanding of effectiveness of mitigation strategies. By incorporating a variety of monitoring techniques the ability to evaluate effectiveness may be improved. The Bennington Bypass study incorporated an array of monitoring techniques in an attempt to understand movement patterns. We here summarize the key findings for each technique.

Small Mammal Mark/Recapture

We captured small mammals and ear-tagged them to assess movement patterns in areas adjacent to the roadway and passageway structures. High disturbance rates from squirrels and raccoons in year 1 required us to change trapping protocol from 5 night sessions conducted once a month to 2 night sessions conducted weekly. This shorter, but more frequent method of trapping allowed for more flexibility around rainy weather and also decreased disturbance rates. We achieved our objective of obtaining an 80% recapture rate by the end of the field season. We found that more frequent, shorter duration trapping periods appear to be an efficient method in areas of frequent precipitation or high disturbance.

We believe that our trap grid design using multiple long transects (500m) provides an optimal design for recording small mammal movements associated with roadways and crossing structures. Further, the strong positive correlation between time and distance moved in our study suggests that trapping periods need to be long to capture the full extent of dispersal movements.

Although additional analyses are still being conducted, the small mammal data were effective in documenting the very high barrier effect of the roadway itself as well as probable use of the expanded bridges by *Peromyscus*. Preliminary results indicate that the highway is a landscape over 200 times more resistant to *Peromyscus* passage as forest. By contrast, the expanded bridges are only approximately 10 times as resistant as adjacent forest. Other small mammal species (voles, jumping mice, chipmunks) were not captured in sufficient numbers for this type of analysis.

An effort was made to test whether “stump rows,” as suggested by Linden (1997), enhanced crossing use by small mammals. In 2007 one stump row was constructed through the WAB structure (Fig. 6.4). However, the material available for constructing the stump row (a combination of small stumps and shrubs) did not provide an amount of cover substantially different from natural vegetation within the expanded bridges. Further, vegetation development within the structures over the course of the study severely limited our ability to interpret trap-recapture data with regards to the stump rows (year-to-year comparisons at WAB; comparisons between WAB and EAB in 2007). As a result we were not able to evaluate the impact of the stump row on small mammal passage.

Monitoring of Mitigation Structures

Monitoring animal movement within the passageways is important in determining whether the structures are functional. We used track beds/plates and remote cameras to obtain information for large and medium sized mammals including: deer, moose, bear, bobcat, fox, coyote, otter, raccoon, opossum, skunk, long tailed weasels, ermine, fisher, woodchuck and mink. Both passageways and one large culvert passage structure were monitored.

1. Track beds

Track beds were located in the middle of the underpasses and track plates at both ends of the culvert. Various track bed methods were experimented with during the first year of our study. Two methods utilizing play sand were utilized: 1) sand laid atop tarp material 1m wide along the entire width of the passageways and 2) sand laid directly on top of existing substrate. Our pilot study revealed that the optimal method was to lay the sand on bare ground after grass, rocks and roots have been removed.

A second group of methods utilizing marble dust was also utilized. Marble dust is a fine powder that allows for the finest resolution of footprints. Three marble dust methods were experimented with: 1) sift the marble dust onto tarp material, 2) sift the dust onto natural substrate and 3) sift the dust onto 4’ X 4’ squares of plywood. We concluded overall that the optimal method was the sifting of the dust onto plywood. The hard foundation allowed for more reliable tracks, required less dust and issues of vegetation growth and uneven surface were alleviated. Marble dust placed atop plywood serves as the preferred tracking substrate for our study but issues of color contrast may need to be addressed in future studies.

2. Track plates

We utilized sooted track plates to monitor the culvert passageway. The track plates consist of 3’ X 3’ sheets of metal, sooted with an acetylene torch. A strip of contact paper was placed in the middle of the metal sheets in order to record the soot laden footprints of animals walking over the plate. One plate was placed on each end of the culvert in order to verify crossings. The plates are checked 2-3 times a week and species, date and direction are recorded. We found that sooted track plates provide higher resolution of animal tracks than any of our track bed methods but are difficult to implement on larger scales, such as spanning our 43 or 56 meter passageways.

3. Remote cameras

A single 35mm camera was rotated bi-weekly among the four sections (streams bisect both passageways) of track bed that are present under the two passageways. Data from this camera was used to confirm track bed data and record animal movements not captured by the track beds. Digital cameras were placed along the streams to monitor those areas not suitable for track bed construction. All cameras were checked weekly.

We concluded that cameras are important for validating track bed data and monitoring areas unsuitable for track beds. Digital cameras (set for 10 – 15 picture sequencing) are excellent tools for recording animal behavior relative to passage structures. They may serve as a low cost alternative to video cameras. The pairing of cameras on opposite sides of a roadway may provide data on wildlife that cross over the roadway rather than through the passages. We found that the Reconyx digital cameras performed much better than the 35mm TrailMaster camera.

Snow Tracking

Snow-tracking during winter provides the opportunity to 1) evaluate animal movements relative to the roadway and passageways, and 2) document the presence of animals in the study area not detected by track beds/plates. The grid design for snow-tracking consisted of four transects parallel to the highway, extending 500m to the east of the East Airport Brook passageway and 500m to the west of West Airport Brook passageway (Fig 3.2). The parallel transects along the highway edge were used to identify movements in relation to the roadway and crossing points. Transects that occurred in the forest allowed us to monitor movements not directly associated with the passageways or roadway. The perpendicular transects provided us with information about the behavior of animals as they approach the passageways and the associated lead fencing. During each snow-tracking day we also checked the passageways for movement through the structures.

Snow tracking sessions occurred 48 hours after snowfalls of ½" or more. We used Palm Pilots with Cybertracker software integrated with GPS to record species, track and gait measurements, gait pattern, direction of movement, markings (e.g. – scat, scent marking), highway location crossings, weather, number of days since last snowfall, snow depth, date and time. During the 2005/06 and 2006/07 snow-tracking seasons, we frequently were not able to walk the entire grid in a single day. When this occurred, we initiated tracking the following day from the last point covered the previous day, weather permitting. Snow plowing typically disturbed the snow pack ~5 meters to either side of the highway, thus areas just beyond the "snowplow zone" were checked carefully to capture tracks headed towards the highway.

From a monitoring perspective, snow-tracking was the most comprehensive method of detecting animal movements. Unfortunately it was viable only during a limited portion of the year and can only be used in latitudes that provide snow cover and in years with sufficient snowfall. It can serve as a low cost alternative to radio telemetry for tracking the general movements of animals through the landscape. It proved to be an effective method for assessing movements of animals not associated with the crossing structures. Information derived from snow-tracking can also be used for placing other monitoring techniques such as cameras and roadside track beds that can monitor movements not associated with passageways in seasons other than winter.

Road Kill Surveys

We began with the hypothesis that if the passageways are effective, road kill rates should be higher in areas farther from the passageways. The entire 7km of the bypass was surveyed for road kills. Surveys were conducted 3 times a week. Driving at 15 mph, each side of the road was monitored and species or group (i.e. – small mammal), direction traveling, and location to the tenth of a mile (using odometer readings) were recorded for each road kill found. In addition, we used monthly traffic counts provided by VTrans to assess the impact of traffic volumes on rates of road kill.

Road kill surveys were most effective for large or mid-sized mammals. In high traffic areas, the majority of small road kill (small mammals, amphibians, reptiles) was unidentifiable. Roadway features such as guardrails, right-of-way vegetative cover, slope of embankments and location of stormwater detention ponds appear to influence rates/species of road kill

Roadside Track Beds

This monitoring technique has great potential. Unlike our snow-tracking sessions, it is difficult in the warmer months to discern animals moving across the highway without the use of radio telemetry. Two pairs of roadside track beds were constructed and monitored along the roadway to monitor highway crossings. The beds are 100' long x 3' wide and constructed using pond fill supplied by VTrans. Pond fill is mud with a silt and clay component that allows it to hold up well in most weather conditions except torrential rain. We constructed these beds in areas where we had observed high use during the previous snow-tracking season. Unfortunately, unusually high rainfall washed out the track beds after installation in both years that we attempted to use this technique.

Although our efforts were ultimately unsuccessful, we believe that roadside track beds have the potential to provide useful data on wildlife road crossings not associated with passage structures in seasons and areas of the country that lack snow cover. Pond fill is an excellent tracking substrate but may require frequent repair during times of high precipitation.

Calling Amphibian Monitoring

To better evaluate the potential changes in amphibian populations over time, we used automated acoustic recording devices (Frogloggers) to monitor the density of calling males at several sites. Following the procedures of Peterson and Dorcas (1994), Frogloggers were set to record for 12 seconds every 10 min throughout the night during the breeding season (March-August). Microphones were suspended above breeding pools from a tree limb to minimize the relative contribution of any single individual to the chorus. Choruses were identified to species and chorus intensity was estimated according to the following scale developed by Mohr and Dorcas. (1999): 1) one individual, 2) distinguishable individuals, and 3) many indistinguishable individuals. Chorus ratings were summed by species to provide a relative index of anuran density at each site (Mohr and Dorcas 1999). Overlapping sites (sites within range of more than one microphone) were excluded from this study to reduce the probability of detecting the same individuals more than once. Recording devices are checked weekly for maintenance purposes.

Frogloggers were placed at the wetland located 200m southwest of the Airport Brook West passageway and at the southern retention pond, located 200m to the west of WAB. Additionally, we are monitoring two ponds along the proposed route of the northwest extension of the Bennington Bypass. These data provide baseline data that can be used in any post construction studies for that section of the highway.

It was our experience that Frogloggers were user friendly and held up well in inclement weather. However, background noise such as crickets and birds can make it difficult to decipher amphibian calls and the process of "transcribing" the tapes can be difficult and time-consuming.

Observational Studies

We tested this method for determining whether animals display evidence of aversion or excessive wariness in the vicinity of the passage structures. Direct observation was also used in an effort to detect animal movement through the passageways that was not captured by the track beds or cameras.

We used night vision goggles to observe animals in the passageways between 1830 hrs and 2230 hrs. An observation period consisted of a 2-3 hour period during which the observer recorded all animal movement and behavior in the passageway. Each passageway was observed 4 times between July 2 and July 29. Only one sighting (a family of raccoons) was recorded using this technique. This method is of limited value due to the number of hours required to obtain significant results.

Snake Distribution and Abundance

Two methods for capturing snakes were deployed during the first year of the study (2005). We intended to use a mark/recapture method using pit tags to monitoring the movement of individual snakes.

The first method involved the use of fence arrays with accompanying funnel traps and pitfall traps. We used 1 meter high drift fence to set up an “X” fence array. Each arm of the array was 5 meters long. Half meter long funnel traps were placed midway along each side of the 4 arms of the array. A second design incorporated the “X” design with a pitfall trap placed at the center of the “X”. The pitfall trap was a sunken 5 gallon bucket. Funnel traps were aligned along each side each side of the 4 arms in this design also. In both designs the funnel traps and pitfall traps served as a passive technique for snake capture.

A second method was the use of cover boards to attract snakes for capture. Cover boards serve as artificial sources of cover and warmth for snakes. We experimented with two types of cover boards. The first was sections of corrugated aluminum and the second was cover boards made of tar roofing sheets, both cut into 1m x 1m squares. The cover boards were placed 10m apart along three 150m transects. The three transects were parallel with the highway, centered on the WAB passage structure. They were placed at three distances from the highway; 1) at the forest edge, 2) 20m from the forest edge and 3) 60m from the forest edge. Two fence arrays were constructed along each transect, one at 50meters and one at 100 meters.

Over a one month period, we only captured one snake using these methods. This portion of the study was discontinued after the first field season. Monitoring of snake movement in New England may require extensive coverage, hence high labor/materials cost, which may be desirable only in areas where certain species of snake are of particular management concern.

RECCOMENDATIONS

We offer the following recommendations for action that can be taken to enhance mitigation success for the current Bennington Bypass project as well as for future projects.

Recommendations for the Current Study Site

1. Replace right-of-way fencing with barrier fencing for the entire area between WAB and EAB and for 2km beyond the expanded bridges in both directions.

Data suggest that fencing plays a key role in mitigation. Animals cross the highway in the highest numbers away from the 8-foot lead fencing, where the 4-foot right of way fencing serves as the only barrier preventing access to the highway. We have documentation that this fencing is easily jumped over or dug under by wildlife (Fig. 6.3). Continued highway crossings by larger mammals (deer, coyote, bobcat, fisher) increases opportunities for road kill and poses risks to public safety from animal-vehicle collisions and drivers swerving to avoid animals in the roadway. The fact that some individuals of these species did use the crossing structures provides some assurance that population continuity can be preserved even if road crossings are eliminated by improved fencing. Consider the construction of escape ramps to provide opportunities for animals that manage to circumvent the fencing to leave the highway alignment.

2. Develop and implement vegetation management plans for the two expanded bridges to optimize woody plant development compatible with maintenance and operation of the highway.

   It seems likely that some of the resistance to using the crossing structures by species such as fisher and *Peromyscus* may have been due to habitat contrast and/or lack of cover within the expanded bridges. Over the three years of this study the growth of woody vegetation beneath the bridges has proceeded quickly. Development of more forest-like conditions within and on the approaches to the structures may help increase mitigation effectiveness for these and other species. Over time, large woody plants will yield coarse woody debris, providing essential cover for small mammals and weasels. To the extent that vegetation will have to be managed as part of maintenance and operation of the highway it would be beneficial to develop and implement vegetation management plans that optimize woody plant growth.

3. Remove large angular rip rap from the entrances of the culvert or use smaller material (e.g. pea stone) to fill the voids in the rip rap and provide a more suitable substrate for wildlife passage.

   Rip rap placed at the entrances of the culvert to prevent erosion is a poor substrate for wildlife passage (Fig. 6.1). The rip rap may be serving as a barrier, inhibiting larger mammals from using the culvert. If possible, the rip rap should be removed from the culvert entrances. If this is not possible, consider whether smaller material such as pea stone can be used to fill the voids and provide a less jumbled substrate for wildlife to cross.

4. Add concrete or another suitable substrate material to culvert bottom throughout the entire length to provide a more suitable alterative to the corrugated metal bottom wildlife must now use when passing through the structure.

    Studies have demonstrated that wildlife use corrugated metal culverts more often when the pipes had concrete bottoms (C. Rosell pers. comm.). It is possible that providing a more suitable bottom substrate would increase the use of the culvert by wildlife.

5. If it is not possible to create a more suitable bottom for the culvert, then remove sills intended originally for trapping and retaining sediment within the structure.

    Thus far, the sills (Fig. 6.2) have not been effective for retaining sediments within the structure. If they provide no other purpose they should be remove as they may well be impeding the passage of wildlife.

6. Repeat select components of this study (small mammal trapping; snow tracking) after the passage of about ten years to better assess changes in mitigation success over time or in response to changes made to fencing or the structures themselves.

    The recommendations listed above are based on best professional judgment from observations made during this study and information gathered from other studies. If some or all of these recommendations are implemented it would be useful to find out whether they resulted in any improvement in wildlife passage. The current study provides an excellent baseline for tracking changes in mitigation success due to time and continued vegetation development or modifications made based on these recommendations.

Recommendations for Future Projects

1. Develop clear mitigation objectives for each species or group of species that are the targets for mitigation; consider the use of metrics to evaluate mitigation success.

2. Ensure that barrier fencing is an element of any mitigation design for terrestrial wildlife.

3. Include consideration of vegetation, including the potential need for vegetation management, as part of mitigation design.

4. Conduct pre-construction monitoring of wildlife movement to identify game trails that might suggest suitable locations for mitigation structures and provide a basis for comparison with post-construction data to more effectively evaluate mitigation success.

   The lack of any pre-construction monitoring for this project has limited our ability to interpret the results of this study. For example, our data indicate that mink and otter used the crossing structures and rarely, if ever, crossed over the road surface. Based on these findings one would conclude that the structures are fully mitigating the highway impacts for these species. However, if pre-construction monitoring revealed that the number of structure crossings was far less than what had occurred in this area prior to highway construction then the mitigation would not be judged to be as successful. Further, pre-monitoring data would have been useful for understanding whether the lack of any crossings by moose, bear, or foxes is due to road avoidance or to a general absence of these species in the area.

   Another benefit of pre-construction monitoring is that it can help identify pre-existing game trails. These game trails might suggest possible locations for crossing structures or barrier fencing. Information about game trails might also provide opportunities for habitat modification (such as re-routing stone walls or cart paths) to make it less likely that animals will try to cross over the road surface and encourage wildlife to use the crossing structures.

5. Use a variety of monitoring techniques (snow tracking, small mammal trapping, track beds and remote cameras) to monitor crossing structures for the broadest range of wildlife species.

6. Use Frogloggers or other suitable technique for pre- and post-construction monitoring to assess changes in amphibian populations as a result of highway projects.

Figure 6.1. Rip rap at culvert entrance.

Figure 6.2. Culvert's corrugated bottom and sills intended to trap and retain substrate material.

Figure 6.3. Deer leaping over right-of-way fencing at the end of the barrier fence.

Figure 6.4. “Stump row” constructed in the West Airport Brook passage structure in 2007.

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